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RADIOLOGICAL MONITORING MANUAL

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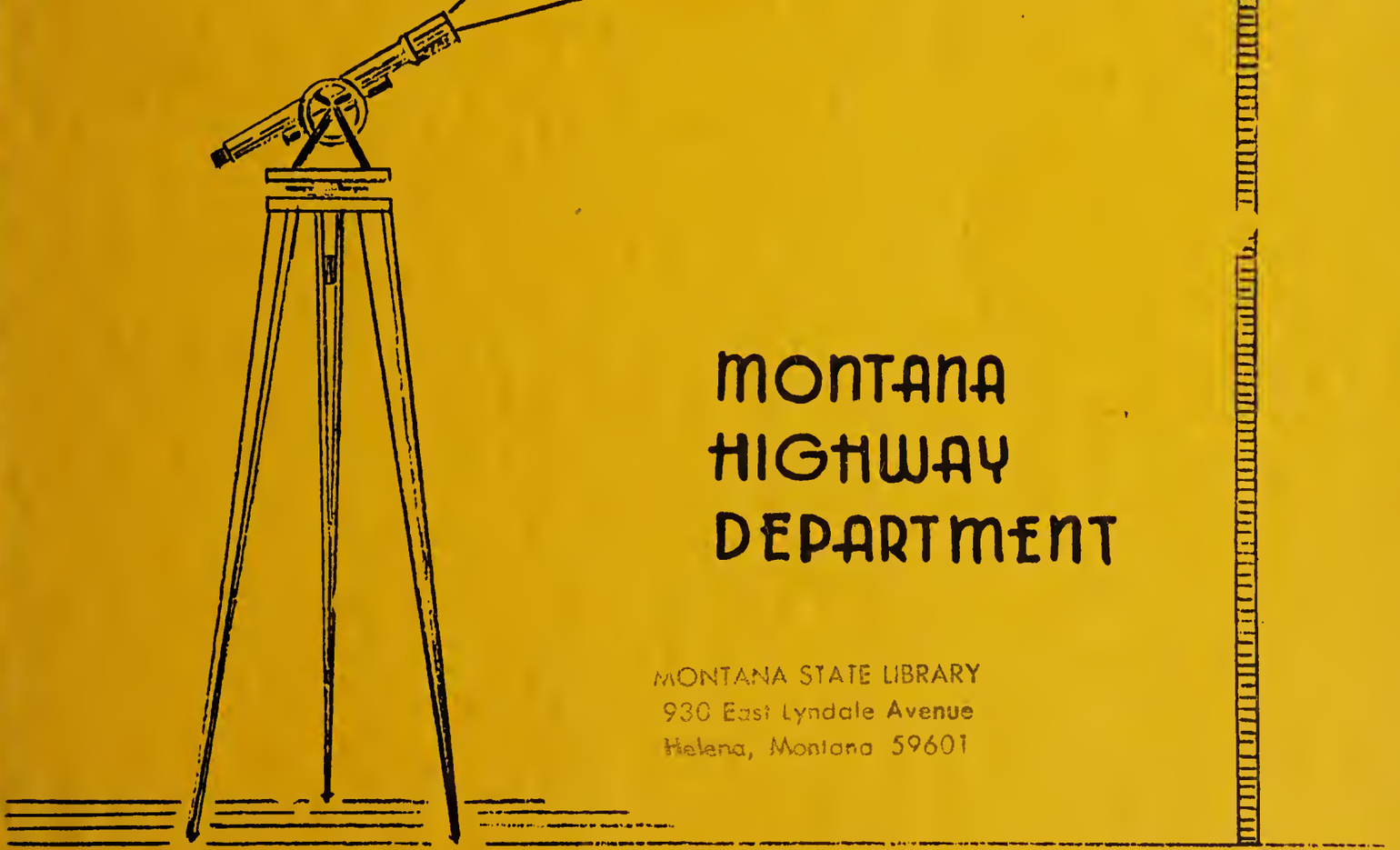

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RADIOLOGICAL MONITORING MANUAL

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INTRODUCTION

This manual has been written to help the members of the Montana Highway Department deal with an atomic attack. It tells how to carry out radiological monitoring, or the determination of the intensity of radiation present by the use of proper instruments.

100 VOCABULARY

Any new subject uses new words. The atomic bomb is only seventeen years old. Some of the words used to talk about it are even newer. The following list explains most of the unfamiliar words used in this subject.

ALPHA PARTICLE	Particle identical with a helium nucleus sent out from the nucleus of a radioactive atom.
ATOM	The smallest particle of an element that can enter into chemical reaction.
BACKGROUND RADIATION	Radiation due to cosmic rays and the natural radioactive materials contained in the earth or building materials.
BETA PARTICLE	Particle identical with an electron sent out from the nucleus of a radioactive atom.
CHAIN REACTION	A chemical or nuclear process in which some of the products of the process or energy generated by the process start other processes which proceed to continue or magnify the process.
COSMIC RAYS	High energy particles apparently coming from outer space.
CURIE	A unit of radioactivity.
DECAY, RADIOACTIVE	A radioactive change in which a nucleus gives off a particle and rays which may form a new element.
DOSE	A quantity of radiation, an accumulated amount received by a person or group of persons.
DOSE RATE	The rate at which a person or group of persons is absorbing radiation in a unit of time, such as an hour.
DOSIMETER	An instrument carried on the person and used to find and measure an accumulated radiation dose.
ELECTRON	A negatively charged particle that revolves around the nucleus of an atom.
ELECTROMAGNETIC RADIATION	For Civil Defense purposes, this term refers to X or gamma radiation.

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ERYTHEMA	An unnatural reddening of the skin due to an overdose of radiation.
FISSION, NUCLEAR	The splitting of a nucleus into two parts with the release of large amounts of heat and radioactivity (Atomic bomb)
FUSION, NUCLEAR	A nuclear reaction in which two light nuclei join to form one heavier nucleus. This is accompanied by the release of large amounts of heat and energy. (Hydrogen bomb)
GAMMA RAY	Electromagnetic radiation sent out from nucleus of radioactive atom, similar to X-rays.
GEIGER COUNTER	Instrument used for the detection and measurement of radioactivity.
HALF-LIFE	Time necessary for one half of a radioactive substance to disappear.
HALF VALUE LAYER	Amount of shielding material necessary to cut the radiation level in half.
INDUCED RADIOACTIVITY	Radioactivity produced by nuclear bombardment usually occurring when a stable atom captures a neutron released by fission.
ION	An atom or group of atoms having an unbalanced electrostatic charge.
IONIZATION	The process of stripping an electron or electrons from their orbits around the nucleus.
IONIZATION CHAMBER	A device roughly similar to a Geiger counter and used to measure radioactivity.
ISOTOPE	An element of the same nature as another element which has the same charge but a different mass.
KILO	Prefix meaning 1,000. e.g. Kiloton equals 1,000 tons.
LD-50	Dose of radiation required to kill, within a certain time, 50% of those exposed.
MASS NUMBER	The sum of the number of protons and neutrons in the nucleus of an atom.
MITOSIS	Division of living cells in the body.
MOLECULE	The smallest part of a compound which can exist and still retain the properties of that compound.
MONITORING	Periodic or continuous determination of the amount of radioactive contamination in an area.

NEUTRON	A particle found in the nucleus of an atom having no electrical charge.
NUCLEUS	The inner core of the atom. It is made up of protons and neutrons tightly locked together.
PERMISSABLE DOSE	Amount of radiation that is not expected to cause noticable bodily injury to a person at any time during his lifetime.
PHOTON	A bundle of radiation. Constitutes, for example, X--rays and light.
PROMPT GAMMA	Radiation sent out at the time of a fission of a nucleus.
PROMPT NEUTRONS	Neutrons given off during fission.
PROTON	A particle found in the nucleus of an atom having a positive charge.
QUANTUM	An elemental unit of energy.
RADIOACTIVITY	The spontaneous, uncontrollable disintegration of the nucleus of an atom with the giving off of particles and rays (alpha and beta particles and gamma rays).
ROENTGEN	The unit for measuring quantities of radiation in studying biological effects.
X-RAYS	Highly penetrating radiation similar to gamma rays.

civil defense
Technical Bulletin

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RADIOLOGICAL DEFENSE SERIES

A DIGEST OF TECHNICAL INFORMATION

RADIATION PHYSICS AND BOMB PHENOMENOLOGY

This is one of a series of technical bulletins on civil defense against the radiological effects of nuclear weapons

This bulletin describes briefly the structure of the atom, how its energy is released in nuclear weapons, and methods of detection and measurement of nuclear radiations.

Structure of Matter

All matter is made up of atoms and combinations of atoms which unite chemically to form molecules. An atom is the smallest unit that retains the properties of an element or can enter into a chemical reaction. For example, common salt, sodium chloride (NaCl), is a combination of one atom of sodium (Na) and one atom of chlorine (Cl). Molecules of single elements may be single atoms or combinations of atoms. For example, one atom of oxygen is represented by O, but the normal oxygen molecule exists as a combination of two atoms, O_2.

Until recently the total number of known elements was thought to be 92, with hydrogen (H) the lightest, and uranium (U), the heaviest. Now, 101 elements have been identified.

All atoms except ordinary hydrogen contain three primary particles, the neutron, proton, and electron. Ordinary hydrogen does not contain a neutron. See Table 1 for characteristics of these particles.

Table 1—Characteristics of Atomic Particles

Name	*Symbol*	*Electrical Charge*		*Mass*
Electron	e	Negative	−1	0.000548 mu*
Proton	p	Positive	+1	1.007575 mu
Neutron	n	None	0	1.00893 mu

*(An atomic mass unit (mu) is 1.6×10^{-24} grams)

The atom may be represented as a solar system consisting of a heavy central mass, the nucleus, with one or more electrons traveling in orbits around it (Fig. 1). The atomic nucleus contains combinations of protons and neutrons. These combinations and the number of electrons vary with the element. To be electrically neutral, an atom must contain the same number of positively charged particles (protons) in the nucleus as negative particles (electrons) in its orbits. The removal of an electron from the orbit produces an ion pair. The free electron is the negative ion and the remaining portion of the atom, the positive ion. The average radius of an atomic nucleus is about 10^{-12} centimeters, and the atom 10^{-8} centimeters.

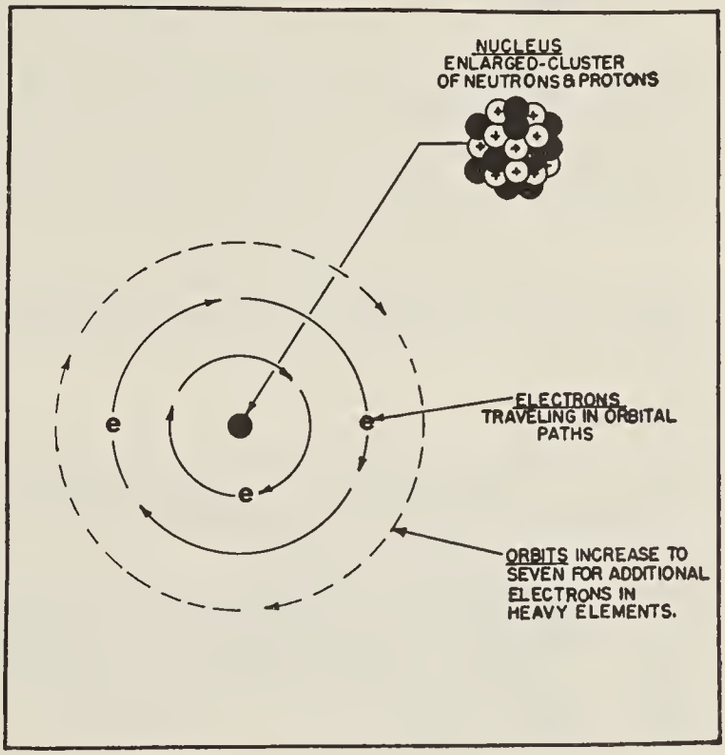


Figure 1—Diagram of an Atom.

Discussion of atomic structure will be simplified by some definitions and symbols that are commonly used.

Z—atomic number. Number of protons in the nucleus of an atom. This number identifies an element. As an example, all atoms of sodium (Na) have a Z number of 11.

A—mass number. Sum of the proton and neutrons in the nucleus of an atom.

N—neutron number. Number of neutrons in the nucleus of an atom.

DEPARTMENT OF DEFENSE
Office of Civil Defense

Isotopes of an element. Forms of the element having the same number of protons in the nuclei, but differing in the number of neutrons. Isotopes of an element have almost identical chemical properties. Any isotope may be represented by the following expression:

$$ {}_{Z}X^{A} $$

where X indicates the element. Examples of 2 isotopes of lithium, $_3Li^6$ and $_3Li^7$, are diagramed in Fig. 2.

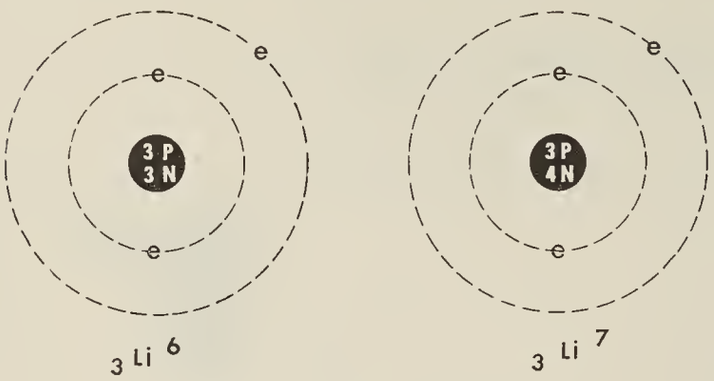


Figure 2—Diagram of Lithium Isotopes.

The difference between these two isotopes is one additional neutron in $_3Li^7$. Both are stable and are mixed in such proportion in nature that the average atomic weight is 6.94.

Radioactivity

Nuclear radiation is energy spontaneously released by an unstable (radioactive) nucleus to attain a more stable state. In certain cases this will result in transmutation — the changing of one element into another.

Some isotopes are naturally radioactive. Also radioactive isotopes may be artificially produced by subjecting a stable nucleus to bombardment by nuclear missiles such as alpha particles, neutrons, or protons. For example, when stable cobalt is bombarded by neutrons having the proper energy, a radioactive isotope of cobalt is formed as shown in the following nuclear equation:

$$ {}_{27}Co^{59} + {}_{0}n^{1} \longrightarrow {}_{27}Co^{60} $$

Stable — Radioactive

Naturally occurring or artificially produced radioactive isotopes emit one or more of three types of radiation. Two of these are particulate—alpha and beta particles; the third is electromagnetic—gamma rays. Alpha particles are positively charged and consist of two protons and two neutrons. Beta particles are high speed electrons. Gamma rays are similar to light and heat waves, but are more energetic. The five senses are unable to detect the presence of nuclear radiation, therefore, a person can become seriously exposed without being aware of it.

The three types of nuclear radiation can be identified by their behavior in a magnetic field. Those slightly deflected by the field are alpha particles, those more easily deflected in the opposite direction, beta particles, and those unaffected, gamma rays. Table 2 summarizes their characteristics.

Table 2—Characteristics of Nuclear Radiation

Radiation	*Symbol*	*Type*	*Mass*	*Electrical Charge*	*Remarks*
Alpha	α	Particle	4.00276 mu	+ 2	Identical to helium atom stripped of its electrons.
Beta	β	Particle	0.000548 mu	−1	Identical to a high-speed electron.
Gamma	γ	Wave	None	None	Electromagnetic wave of energy.

Nuclear stability is determined primarily by the number of neutrons relative to the number of protons in the nucleus. For those isotopes having low atomic numbers, maximum stability is obtained when the n/p ratio is about 1. As the atomic numbers get larger, this ratio increases to about 1.5. When the number of neutrons in the nucleus differs greatly from the optimum ratio, the atom is radioactive. Radioactive elements up to a mass number (A number) of 80 are usually beta and gamma emitters, while those over 210 are alpha emitters. Where the n/p ratio is below the range for maximum stability, a positron ($\beta+$) may be emitted. A positron has the mass of an electron but is positively charged.

Nuclear reactions can transmute one element into another. The bombardment of nitrogen by alpha particles having the proper energy produces a stable isotope of oxygen and a proton and is illustrated by the equation:

$$ {}_{7}N^{14} + {}_{2}\alpha^{4} \longrightarrow {}_{8}O^{17} + {}_{1}p^{1} $$

Stable — Stable

Energy may be imparted to nuclear missiles in particle accelerators such as cyclotrons, synchrocyclotrons, and bevatrons.

Capture or loss of a particle by the nucleus leads to the formation of a new isotope. If this isotope has an excess of nuclear energy, it is radioactive. It becomes stable after this surplus energy is released.

The conversion of mass to energy is explained by Einstein's famous theory of relativity. This relationship is represented by the equation, Energy = Mass times a constant, which is the square of the speed of light, ($E = mc^2$); if E is measured in ergs, m is in grams, then c is the velocity of light in centimeters per second. The following equation shows that an extremely small change in the mass of a system produces a very large amount of energy:

Equation:

Boron 10 + alpha → Carbon 13 + proton + E

where E represents the energy released

Eq. in Symbols:

$$ {}_{5}B^{10} + {}_{2}\alpha^{4} \longrightarrow {}_{6}C^{13} + {}_{1}p^{1} + E $$

Nucleus — Nucleus

Mass in mu:

$$ 10.01344^{*} + 4.002764 = 13.004222^{*} + 1.007575 + E $$

$$ 14.016204 = 14.011797 + E $$

$$ 0.004407 = E $$

Energy equivalent: E = 4.1 Mev.

*The mass of a nucleus is smaller than the combined masses of the individual particles. The difference represents binding energy of the nucleus.

The difference in mass on the two sides of this equation is 0.004407 mass units which is transformed to energy. In this case the energy is equal to about 4.1 million electron volts (Mev). This might be compared to the energy of about 15-20 electron volts obtained from burning a single molecule of gasoline.

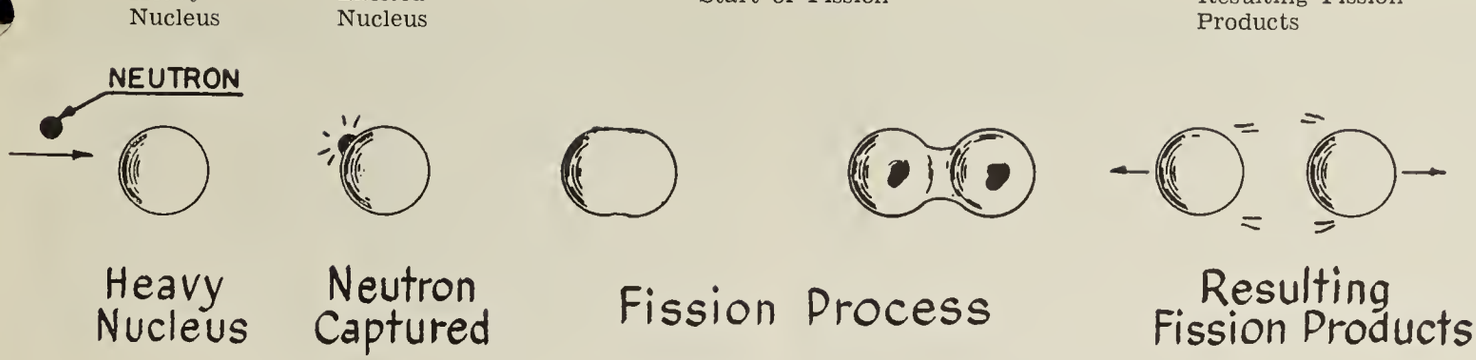


Figure 3—Fission Process.

Fission Process

The neutron is electrically neutral and is not repelled by the electrostatic field surrounding the nucleus. Therefore, it is more easily captured by the nucleus than a charged particle.

The bombardment of a heavy element such as uranium with neutrons may result in a reaction in which the nucleus splits into smaller nuclei with the release of a relatively enormous amount of energy. This is called fission. Although theoretically it is possible to obtain fission energy from all elements heavier than silver, practically, only uranium, plutonium, and thorium are useful for this purpose.

When fission takes place and a heavy nucleus breaks into lighter nuclei—called fission products—the energy released is about 200 Mev. About 0.1% of the mass of the uranium atom is converted into energy. The energy released from fissioning 1 kilogram of U^{235} is about 8×10^{20} ergs, equivalent to the energy produced by burning about 3,500 tons of high-grade coal. The fission process is illustrated in Figure 3.

The fission process results in random splitting of the nucleus. Usually two, but sometimes three, fission products are produced. More than 200 fission products have been identified. Figure 4 shows the mass distribution of fission products. Most of them are radioactive. The radioactive fission products decay to stable atoms by emitting beta and gamma rays. Fission products are not alpha or neutron emitters.

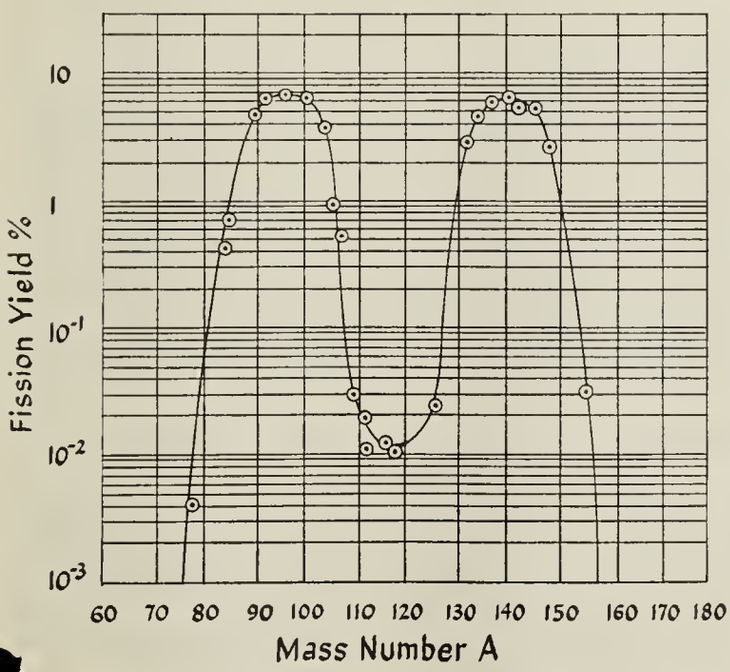


Figure 4—Mass Distribution of Fission Products.

THE ATOMIC BOMB

Fission is accompanied by the release of neutrons. The neutrons in turn may be captured by other nuclei and cause successive fissioning. This chain reaction (Fig. 5) makes possible the nuclear reactor and atomic bomb. In the reactor or pile, the fission rate is controlled by absorbing some of the neutrons. In the bomb, the reaction is not slowed and the chain reaction is completed in a fraction of a second.

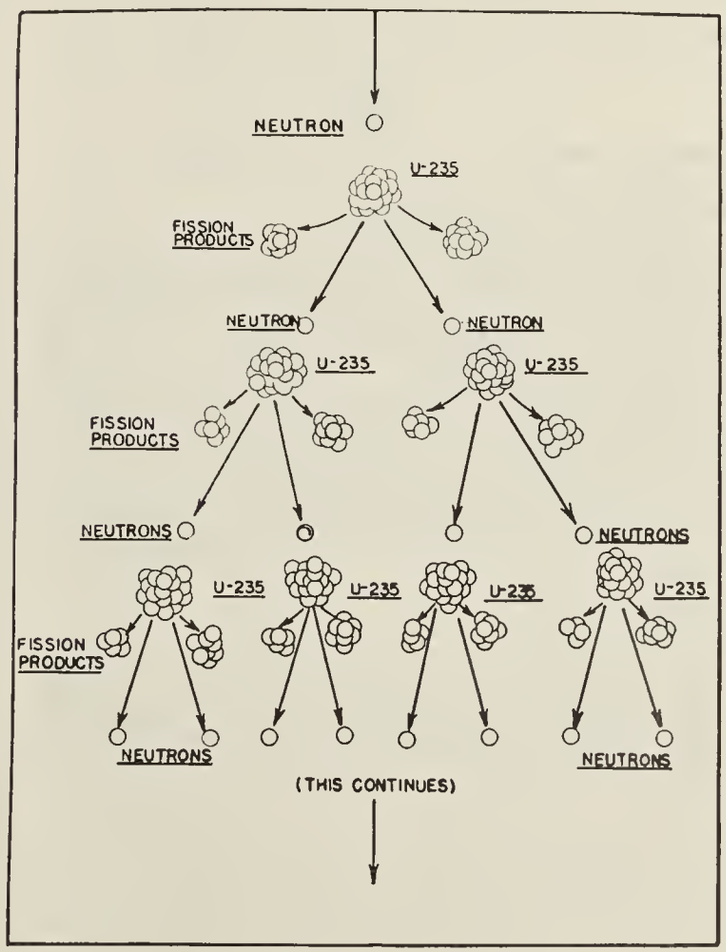


Figure 5—Diagram of Chain Reaction.

Energy released from the explosion of an atomic bomb produces the same three effects as an explosion of TNT; light, heat, and blast. In addition, the emission of nuclear radiation occurs. *Initial* radiation is composed of neutrons, gamma, and beta radiation, and lasts for about one minute after the detonation. The beta radiation, because of its short path length, does not contribute to the hazard. *Residual* radiation is gamma and beta rays from the fission products, alpha particles from the unfissioned uranium or plutonium, and beta and gamma radiation from substances made radioactive by neutrons released at the time of burst.

When a ground burst occurs, debris and dirt are sucked into the ascending cloud. Vaporized fission products, bomb fragments, and neutron-induced radioactive elements condense on this material. These contaminated particles which settle to the ground are called fallout. High air bursts do not produce significant fallout hazard because surface material is not carried into the cloud for the radioactive particles to condense upon.

Fusion

The fusion process, in contrast to the breaking up a heavy nucleus as is done in fission, combines two nuclei of light elements into a heavier one. Such reactions may be used to produce energy. The fusion process is the source of solar energy and requires temperatures of millions of degrees. The following equation is an example of the fusion reaction:

Equation:

Hydrogen 3 + Hydrogen 1 ⟶ Helium 4 + Energy

Eq. in Symbols:

$$_1H^3 + {}_1H^1 \longrightarrow {}_2He^4 + E$$

Nucleus Nucleus Nucleus

Mass in mu:

$$3.016472 + 1.008123 = 4.002764 + E$$
$$4.024595 = 4.002764 + E$$
$$0.02183 = E$$

Energy Equivalent:

$$E = 20 \text{ Mev.}$$

THE THERMONUCLEAR BOMB

Because the fission bomb produces the high temperature required for the fusion process, it serves as a trigger for the fusion device. The term "hydrogen bomb" has been used because one possibility for the bomb is based on the fusion of isotopes of hydrogen.

The same type of initial and residual radiation results from the thermonuclear bomb as with the fission weapon, but to a greater degree. A thermonuclear bomb will probably be detonated so that it touches the ground. Great quantities of surface material would be taken up into the cloud for the vaporized fission products and bomb fragments to condense upon. This greatly increases the fallout problem.

Multiple Decay

Each radioactive isotope has a characteristic half-life. These range from a few millionths of a second to millions of years. However, when many elements—in this case the fission products of a bomb—are present, no one half-life applies for the composite. With fission products there is a predominance of short-lived radioisotopes in the period immediately following the burst; hence the radiation level falls off very rapidly. As these expend themselves, the longer half-life isotopes become more dominant and the decay rate of the fission products decreases.

Multiple radioactive decay for fission products may be calculated by using Kaufman's equation for multiple decay, $K = IT^n$, where K = dose rate at unit time; I = dose rate at any time T, measured from the time of burst, and n is the Kaufman exponent (Fig. 6). Time may be measured in any units—minutes, hours, days, weeks, etc. A more familiar form of this equation is $I = I_1 t^{-n}$. Where I is the activity at any time t, I_1 is the dose rate at unit time, and n is the Kaufman exponent. The value of n is not fixed; it may vary with bomb design, location of burst, and the amount and type of neutron-induced activity. For a particular contaminated area, decay may be affected by weathering and decontamination. For planning purposes, a value of n = 1.2 may be used. Accurate information on the radiation levels and rate of decay must depend on radiological surveys. (See table 1, appendix A.)

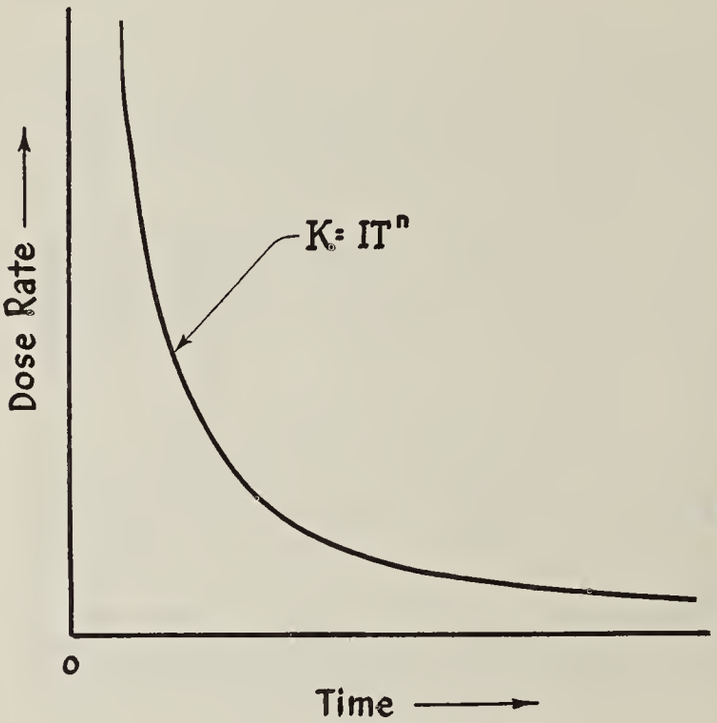


Figure 6—Multiple Decay.

Cumulative Dose

The total cumulative radiation dose and the time period in which it was received by a person is important when deciding if a person should be further exposed in civil defense operations. Dose is equal to the dose rate multiplied by time of exposure. (Dose = Dose rate x Time). This is easy to calculate when the radiation level remains essentially constant over a long period of time, as it does with a long-lived radioactive isotope.

In calculating dose from fallout radiation, the rapid decrease in radiation level must be taken into account. From the equation $D = \frac{K}{n-1} [\, t_1^{1-n} - t_2^{1-n} \,]$, the dose accumulated between the time of entrance (t_1) into a contaminated area and time of exit (t_2) can be calculated. D is the dose received, K = Intensity at unit time, and n is Kaufman's constant. (See appendix A.)

The percentage of total dose accumulated during a portion of the exposure time is shown in Table 3.

Table 3—Accumulated Dose

Total dose received in:	Percent total dose for following exposure time in hours												
	4	8	12	16	20	24	36	48	72	96	120	336	720
(hours)	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent	Percent
4	100												
8	78	100											
12	69	88	100										
16	64	82	92	100									
20	60	78	88	95	100								
24	58	74	84	91	96	100							
36	53	69	78	84	89	92	100						
48	51	65	74	80	84	88	95	100					
72 (3 days)	48	61	69	75	79	82	89	94	100				
96 (4 days)	46	59	66	72	76	79	86	90	96	100			
120 (5 days)	45	57	65	70	74	77	83	88	93	97	100		
336 (14 days)	40	51	58	63	66	69	75	79	84	87	90	100	
720 (30 days)	38	48	55	59	62	65	70	74	79	82	84	94	100

(Assuming n = 1.2 and the exposure starts 1 hour after burst)

For example: If the total dose were received in 48 hours, over ½ of it was received in the first 4 hours of exposure. If the total dose were received in 14 days, over half was received in the first 8 hours and about 75% in the first 36 hours.

Detection and Measurement of Radiation

Generally, instruments measure an effect of a phenomenon rather than the phenomenon itself. The sensitivity of radiation instruments depends on the ionizing effect of radiation. Most of these instruments measure the amount of ionization produced in a gas. Ionization of a gas consists of the removal of one or more electrons from one or more of the gas molecules, changing the electrically neutral molecules into positive ions. Civil defense survey meters and self-reading dosimeters are instruments of this type. In the presence of an electrostatic field, these positive ions are moved in one direction while the electrons are moved in the opposite direction. The measurement of the amount of current thus created provides an indication of radiation level. Usually a closed tube having an electrically conducting shell and insulated central electrode, containing a definite volume of gas, is used as the radiation sensitive element of the instrument. Other instruments such as the phosphate glass and chemical dosimeters depend on ionization phenomena which change their molecular arrangement and consequently their optical characteristics.

GEIGER COUNTER

The geiger tube is filled with inert gas such as neon or argon and small amounts of organic or halogen vapor. The amount of ionization produced inside the tube by the primary radiation is amplified by the inert gas in an avalanche effect, producing a pulse of current which activates an electric circuit. The organic or halogen vapor acts to terminate the pulse and restore the tube to its sensitive condition. Geiger counter instruments are useful for many purposes because of their sensitivity. Their primary use in civil defense operations would be for monitoring food, water, and people for radioactive contamination. They are particularly adaptable for training since they can be operated in weak radiation fields, minimizing radiation exposures to trainees. Geiger counters do not read true dose rates in roentgens per hour unless measuring a known radiation energy for which the instrument has been previously calibrated. They read numbers of ionizing events without regard to the energy of these events. From a practical standpoint in civil defense, true roentgen readings in the low radiation levels for which a geiger counter is used are not important. The OCD geiger counter, CD V-700[1], is calibrated against radium or cobalt 60 gamma radiation and will not give a true dose rate in roentgens per hour for the lower energy gamma radiation given off by fallout.

IONIZATION CHAMBER SURVEY METER

Ionization produced in the radiation sensitive chamber of the instrument is measured directly with an extremely sensitive electronic circuit. Electric current produced by this ionization passes through extremely high value resistors developing voltages which are fed into the grid of a special vacuum tube and amplified. Since minute currents are involved, special insulators, large value resistors, and "electrometer" tubes are required.

Collecting all of the ions produced becomes a problem, especially on the higher ranges. If the batteries are weak, the instrument may calibrate accurately at low readings but indicate less than the actual value in higher fields. For this reason, the batteries supplying the ionization chamber must be up to their rated value, particularly if the instruments are to be used in high radiation fields.

The instruments CD V-710 and CD V-720[1] are ionization chamber survey meters. CD V-710 measures gamma only; the ionization chamber is protected by sufficient material to completely absorb alpha and beta radiation. CD V-720 may be used to detect gamma radiation only, or with its sliding shield in the open position, it responds to beta radiation as well. The instrument does not indicate beta radiation directly since the contribution from a gamma component will have to be subtracted. Even then a calibration chart must be used for proper interpretation.

DOSIMETER

The self reading ionization chamber dosimeter may be described as an electrical condenser in parallel with a high-impedance voltmeter. The condenser is charged to give a

[1] See TB-11-20, Revised May 1959. Radiological Instruments for Civil Defense.

"zero roentgen" indication on the voltmeter. Radiation entering the sensitive chamber of the dosimeter produces ions which are collected by the electrodes of the chamber causing a reduction in voltage. The amount of this reduction is indicated on the meter as a particular radiation exposure. In the CD V-730 and CD V-740[1], "zero roentgens" correspond to about 170 volts while "full scale" corresponds to about 110 volts. The ionization chamber dosimeter requires exceptionally good insulation, since the instrument must be capable of holding its charge when no radiation is present. This requires insulation many million times better than that required in an ordinary radio. Dosimeters must be capable of accurately indicating the doses received at extremely high rates. Two factors may cause difficulties: (1) not all of the ions are collected or (2) the insulators lose ability to hold the electric charge, resulting in an apparent dose reading. Dosimeters produced in accordance with OCD specifications do not exhibit these characteristics.

Glossary

Following are terms commonly used in radiological defense:

Absorption—The process by which the energy of radiation is reduced as it passes through matter. Absorbed radiation may be transformed into matter, other radiation, or energy by interaction with the electrons or nuclei of the atoms with which it reacts.

Absorption Coefficient—The fractional decrease in the intensity of a beam of radiation per unit thickness or unit mass of the absorbing material.

Alpha Particle—Nuclear radiation consisting of two protons and two neutrons and having a double positive charge. It is identical to a helium nucleus. Alpha particles can be stopped by a few inches of air, by a sheet of paper, or the dead surface layer of the skin.

Alpha Emitters—Radioactive materials which emit alpha particles. Certain of these substances have an affinity for bone tissue, have long half-lives, and tend to remain in the bone for long periods of time. They are therefore dangerous if taken into the body, since the emitted alpha particles can cause cell damage in the immediate area where the substances become located.

Avalanche—A process in which a single charged particle accelerated by a strong electric field produces additional charged particles through collision with neutral gas molecules.

Beta Particle—A negatively charged particle emitted from the nucleus of an atom and having a mass and charge equal in magnitude to an electron. Beta radiation may penetrate about a half a centimeter into the skin, producing an effect similar to a burn. Beta particles are more highly ionizing.

Beta Emitters—Radioactive materials which emit beta particles. These substances taken internally can cause serious cell damage.

Curie (c)—The amount of radioactive material which decays at the rate of 3.7×10^{10} disintegrations per second. A millicurie (mc) is one thousandth of a curie; a microcurie (μc) one millionth.

Electron Volt (ev)—The amount of energy gained by an electron in passing through a potential difference of one volt. A million electron volts is abbreviated Mev. 1 Mev equals 1.6×10^{-6} ergs. 931 Mev equals 1 atomic mass unit.

Erg—A unit of work or energy. A million ergs equals 0.1 watt-seconds. A billion ergs equals 24 calories.

Gamma Rays—Short wave length electromagnetic radiations emitted from the nucleus of an atom. They have no mass or electrical charge. They may travel several thousand yards in air, and can completely penetrate the body.

Half-life, Physical—The time required for a radioactive substance to lose 50% of its activity by decay. Each radioactive isotope has its own characteristic half-life; it ranges from a millionth of a second to billions of years.

Ion—An atomic particle, atom, or group of chemically combined atoms that have an electric charge, either positive or negative.

Ionization—The process by which a neutral atom or molecule acquires either a positive or negative charge. A high speed particle passing through matter may cause the atom or molecule to divide into positive and negative parts called ions, destroying the electrical balance (Fig. 7).

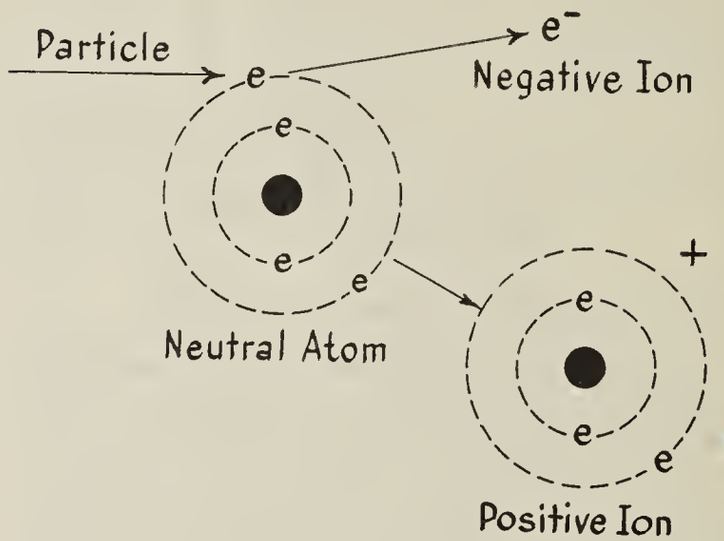


Figure 7—Ionization.

Ionizing Radiation—Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly. Gamma rays, beta and alpha particles, and neutrons are ionizing radiations of concern in radiological defense.

Neutron—Electrically neutral particle having a mass approximately the same as the hydrogen atom. Neutrons are released in the processes of fission and fusion. They are not emitted by radioactive fallout particles.

Residual Radiation—Nuclear radiation emitted by radioactive materials produced by the explosion of a weapon and including unfissioned bomb material.

Rigged Bomb—A nuclear bomb to which an element, such as cobalt, is added to increase neutron-induced radioactivity for the purpose of increasing contamination by fallout. The Department of Defense has called the cobalt bomb "impractical."

Roentgen—A unit of radiation quantity, defined as that amount of X- or gamma radiation which produces one electrostatic unit of charge of either sign in one cubic centimeter of air at standard temperature and pressure.

X-rays—Penetrating electromagnetic radiations identical to gamma rays, but generally less energetic. X-rays originate in the electron structure of an atom and may be produced by the sudden slowing down of high speed electrons as in the X-ray machine, or by the "jumping" of electrons from an outer to an inner orbit.

APPENDIX A

Calculating Dose From Fallout Radiation

Example:

What dose would a civil defense team receive due to a nuclear burst if the team entered a contaminated area 5 hours after the burst and the team stayed for a period of 16 hours. The dose rate at one hour after the burst was 50 r/hr.

Solution:

Using the formula found on page 4.

$$D = \frac{K}{n-1} [t_1^{1-n} - t_2^{1-n}]$$

$n = 1.2$
K = Intensity at unit time
t_1 = Time of entry
t_2 = Time of exit
D = Dose received in r.

By substituting values in the above formula

$$D = \frac{50}{1.2-1} [5^{1-1.2} - 21^{1-1.2}]$$

$$= \frac{50}{.2} [5^{-0.2} - 21^{-0.2}]$$

Referring to table 1 of appendix A, we find that:

$5^{-0.2} = 0.725$
$21^{-0.2} = 0.544$

Therefore:

$D = 250 [0.725 - 0.544]$
$= 250 \times 0.181$
$= 45r$

Table 1

t = Time in hours	$t^{1.2}$	$t^{-0.2}$
0.1	0.0631	1.586
0.2	0.1450	1.381
0.3	0.2358	1.273
0.4	0.3330	1.202
0.5	0.4352	1.149
0.6	0.5417	1.110
0.7	0.6518	1.074
0.8	0.7651	1.046
0.9	0.8812	1.023
1.0	1.000	1.000
1.5	1.627	0.921
2.0	2.300	0.871
2.5	3.003	0.826
3.0	3.737	0.803
4.0	5.278	0.756
5.0	6.899	0.725
6.0	8.586	0.697
7.0	10.33	0.679
8.0	12.13	0.660
9.0	13.96	0.644
10.0	15.85	0.631
11.0	17.77	0.619
12.0	19.73	0.608
13.0	21.71	0.599
14.0	23.74	0.590
15.0	25.78	0.582
16.0	27.86	0.574
17.0	29.28	0.567
18.0	32.09	0.560
19.0	34.23	0.555
20.0	36.41	0.550
21.0	38.61	0.544
22.0	40.82	0.539
23.0	43.06	0.534
24.0	45.31	0.530
25.0	47.59	0.525
25.5	48.74	0.523
26.0	49.89	0.521
27.0	52.20	0.518
28.0	54.52	0.514
29.0	56.87	0.510
30.0	59.23	0.505
31.0	61.61	0.503
32.0	64.00	0.500
33.0	66.41	0.497
34.0	68.83	0.494
35.0	71.27	0.491
36.0	73.72	0.488
37.0	76.18	0.486
37.5	77.43	0.484
38.0	78.66	0.483
39.0	81.15	0.480
40.0	83.67	0.478
41.0	86.17	0.476
42.0	88.70	0.474
43.0	91.23	0.472
44.0	93.79	0.470
45.0	96.35	0.467
46.0	98.93	0.465
47.0	101.5	0.463
48.0	104.1	0.461
49.0	106.7	0.459
49.5	109.0	0.458
50.0	109.3	0.457
55.0	122.6	0.449
60.0	136.1	0.441
65.0	149.8	0.434
70.0	163.7	0.427
72.0	169.4	0.425
75.0	177.8	0.422
80.0	192.2	0.417
85.0	206.7	0.412
90.0	226.5	0.407
95.0	236.2	0.402
96.0	239.2	0.401
100.0	251.2	0.399
120.0	312.6	0.384
140.0	376.2	0.372
144.0	389.1	0.370
160.0	442.5	0.362
168.0 (1 wk)	468.1	0.360
180.0	508.5	0.354
200.0	577.1	0.347
250.0	754.3	0.333
300.0	938.7	0.319
336.0 (2 wk)	1075.0	0.313
504.0 (3 wk)	1745.0	0.288
672.0 (4 wk)	2471.0	0.272
720.0 (1 Mo.)	2611.0	0.268
1440.0 (2 Mo.)	6166.0	0.234
2160.0 (3 Mo.)	10031.0	0.216
4320.0 (6 Mo.)	23045.0	0.187
8640.0 (1 Yr.)	52943.0	0.163
17280.0 (2 Yr.)	121640.0	0.143
25920.0 (3 Yr.)	197860.0	0.131
34560.0 (4 Yr.)	279430.0	0.124
43200.0 (5 Yr.)	365240.0	0.118
86400.0 (10 Yr.)	839100.0	0.102
216000.0 (25 Yr.)	2519700.0	0.086

APPENDIX B

Graphical Solution of Dose From Fallout Radiation

Example:

Using the same example as given in appendix A, the solution by graph is as follows: See chart 1 of appendix B.

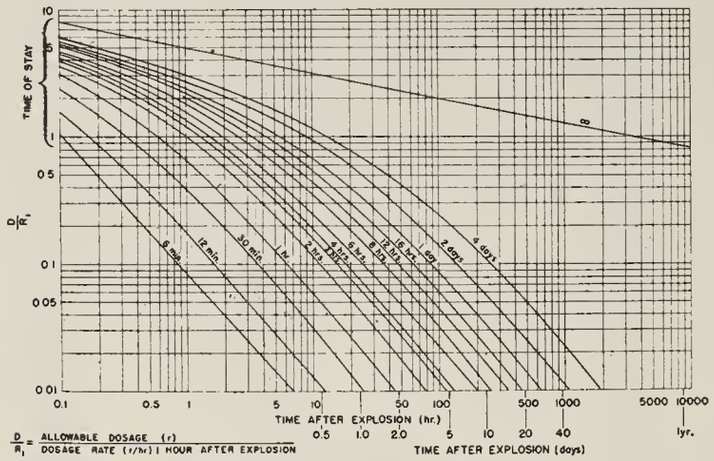

TIME OF STAY
D/R1
TIME AFTER EXPLOSION (hr.)
TIME AFTER EXPLOSION (days)
D/R1 = ALLOWABLE DOSAGE (r) / DOSAGE RATE (r/hr) 1 HOUR AFTER EXPLOSION

Chart 1

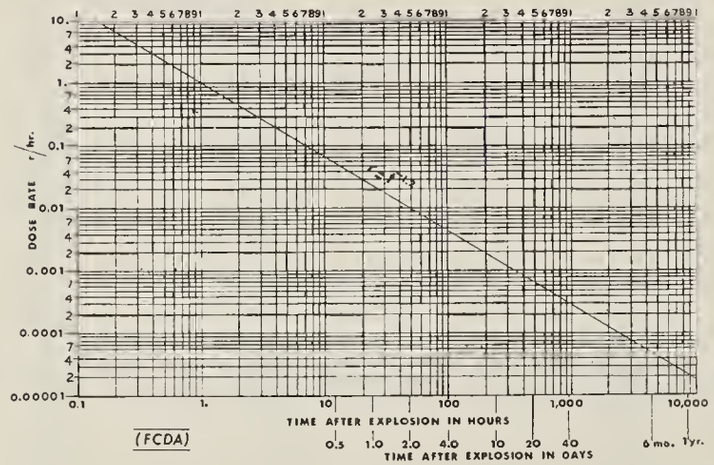


Chart 2

Solution:

The point of intersection of the 5-hour **after-the-explosion** line and the 16-hour **time-of-stay** line lies on the $\frac{D}{R_1}$ line and is equal to .9

D = Dose (r)

R_1 = Dose rate (r/hr) 1 hour after explosion

$\frac{D}{R_1} = .9$

or

$D = .9 \times R$ or $.9 \times 50 = 45$ r

To determine the approximate dose rate at H+1:

1. Determine the time after explosion of your measurement.

2. Locate the point of intersection with time after explosion line (chart 2) and the decay line, $r = t^{-1.2}$. Read the dose rate (r/hr) on the left axis.

Example:

A radiological monitor records a reading of 6.3r/hr at 10 hours. What was the dose rate H+1.

Solution:

$$\text{Dose rate (r/hr) at H+1} = \frac{\text{meter reading at specific time}}{\text{Value read from chart 2}}$$

$$= \frac{6.3}{.07}$$

= Approximately 90 r/hr

To determine the approximate dose rate at any time:

Example:

If the meter reading is 6.3 r/hr at H+10, what will the dose rate be at H+20?

Solution:

$$\frac{\text{Dose rate (r/hr) as measured}}{\text{Dose rate (r/hr) at new time}} = \frac{\text{Dose rate (r/hr) from chart 2 at time of measurement}}{\text{Dose rate (r/hr) from chart 2 at time selected}}$$

By substitution:

$$\frac{6.3}{\text{Dose rate at H+20}} = \frac{.07}{.03}$$

Cross multiplying:

$$\text{Dose rate at H+20} = \frac{.03 \times 6.3}{.07}$$

= 2.7 r/hr

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C.—Price 5 cents.

GPO 815104

ATOMIC EXPLOSIONS

210 General

An atomic explosion is much like a TNT explosion in that most of its destruction comes from the blast of the bomb. However, there are three important differences between the two. They are:

211 Thermal Radiation

Large amounts of light and heat given off by an atomic bomb. Can burn the skin and start fires.

212 Initial Nuclear Radiation

Highly harmful and penetrating rays given off at the moment of the explosion. Can cause sickness or death.

213 Residual Nuclear Radiation

Radioactive debris left after the explosion. Can cause sickness or death.

220 Positions and Effects of Atomic Explosions

221 Air Burst

a. Fireball does not touch surface of earth.

b. Large amounts of thermal radiation.

c. Little residual radiation.

d. Most damage caused by blast.

222 Surface Burst

a. Fireball touches surface of earth.

b. Low thermal radiation.

c. Much residual radiation.

d. Most damage from blast and initial radiation.

223 Underground Burst

a. Fireball under surface of earth.

b. Very little thermal or initial radiation.

c. High residual radiation.

d. Damage caused by blast and residual radiation.

230 Hazards of Nuclear Explosions

231 Blast

a. Direct: Caused by force of wind after explosion; broken ear-drums, internal bleeding, etc.

b. Indirect: Caused by debris thrown about by explosion; fractures, cuts, brusies, etc.

232 Burn

a. Flash Burn: Caused by thermal radiation; does not form blisters but can char skin if intense enough.

b. Fire Burn: Same as ordinary burn; caused by burning debris or clothing.

233 Radiation

Damages cells of the body. Cannot be seen or felt. Too much exposure to radiation can cause sickness or death.

CHART NO. 1

APPROXIMATE RADIATION DOSES COMMONLY ENCOUNTERED

Cosmic and Background	0.0003 r/day.
Chest X-ray	0.05 r/film.
Fluoroscopy	0.3 r/sec.
Dental film	5 r/film.
X-ray shoe fitting machine	10-15 r/fitting.

Reference:
Physics today 5:10-16 (1952)
Nucleonics 10:16-20 (1952)

CHART NO. 2

PHYSIOLOGICAL RESPONSE TO GAMMA RADIATION

LD 50

Man	=	450-500r.
Swine	=	450r.
Mouse	=	590r.
Rabbit	=	790r.
Chicken	=	1000r.
Cattle	=	750r.
Sheep	=	350r.
Guinea Pig	=	175-250r.
Dog	=	325r.
Rat	=	800-900r.
Jackass	=	450r.

References:

Comar - Radioisotopes in Biology and Agriculture. 1955

CHART NO. 3

Estimated Medical Effects of Radiation Doses Expressed as Percentage of Working Force Affected *

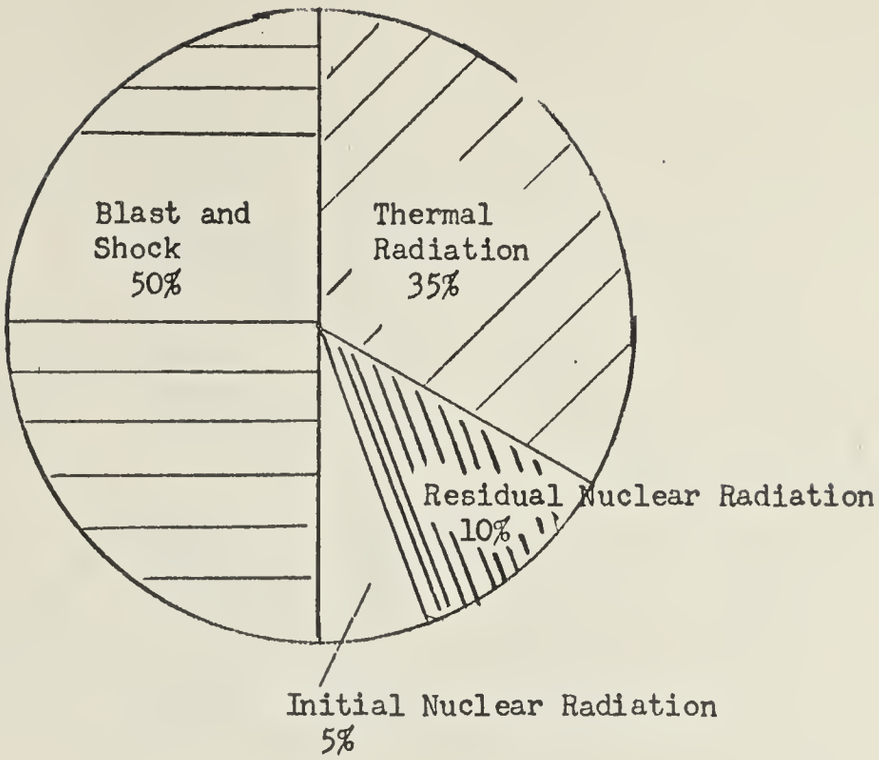
Total Dose (r)	Early Effects for Periods of Time Over Which Total Dose is Received					Late Effects
	1 Day	3 Days	1 Week	1 Month	3 Months	
0 to 75	0% sick				0% sick	None
100	2% sick**	0% sick			0% sick	None
125	15% sick	2% sick	0% sick		0% sick	None
150	25% sick**	10% sick	2% sick	0% sick	0% sick	None
200	50% sick**	25% sick	15% sick	2% sick	0% sick	Some late Effects
300	100% sick** 20% die**	60% sick 5% die	40% sick	15% sick	0% sick	Some late Effects
450	100% sick** 50% die**	100% sick 25% die	90% sick 15 % die	50% sick	0-5% sick	Some late Effects
650	100% sick** 95+% die**	100% sick 90% die	100% sick 40% die	80% sick 10% die	5-10% sick	Some late Effects

* This table applies to healthy, young adults under usual working conditions.
The percentage of fatalities will be decreased with adequate medical treatment.
The percentage figures are based on an interpretation of the best current available evidence and may be changed as more information is accumulated.

**Based on NAVMED P-1330, Army pamphlet No. 8-11, and Air Force Manual AFM 160-11.

CHART NO. 4

Time after Exposure	Lethal dose (650r)	Median lethal dose (400r)	Moderate dose (300 to 100r)
	Nausea and vomiting after 1-2 hours	Nausea and vomiting after 1-2 hours	
First Week	No definite symptoms	No definite symptoms	
	Diarrhea Vomiting		
- - - - - - - - -	Inflamation of mouth and throat	No definite symptoms	
Second Week	Fever Rapid emaciation Death (Mortality probably 100 per cent)	Beginning epilation Loss of appetite and General malaise	No definite symptoms
Third Week		Fever	Epilation
- - - - - - - -		Severe inflamation of mouth and throat	Loss of appetite and general malaise Sore throat
Fourth Week		Pallor Petechiae, diarrhea, and nose bleeds Rapid emaciation Death (Mortality probably 50 per cent)	Pallor Petechiae Diarrhea, Moderate emaciation (Recovery likely unless complicated by poor previous health)



Distribution of Energy in Typical Nuclear Detonation

Burn Chart

Bomb Size in Kilotons	Degree of Burn		
	1st	2nd	3rd
20	2.4 miles	1.6 miles	1.4 miles
200	6.4 miles	4.4 miles	3.8 miles
1,000	13.0 miles	9.0 miles	8.0 miles
5,000	25.0 miles	18.0 miles	15.0 miles
20,000	44.0 miles	32.0 miles	28.0 miles

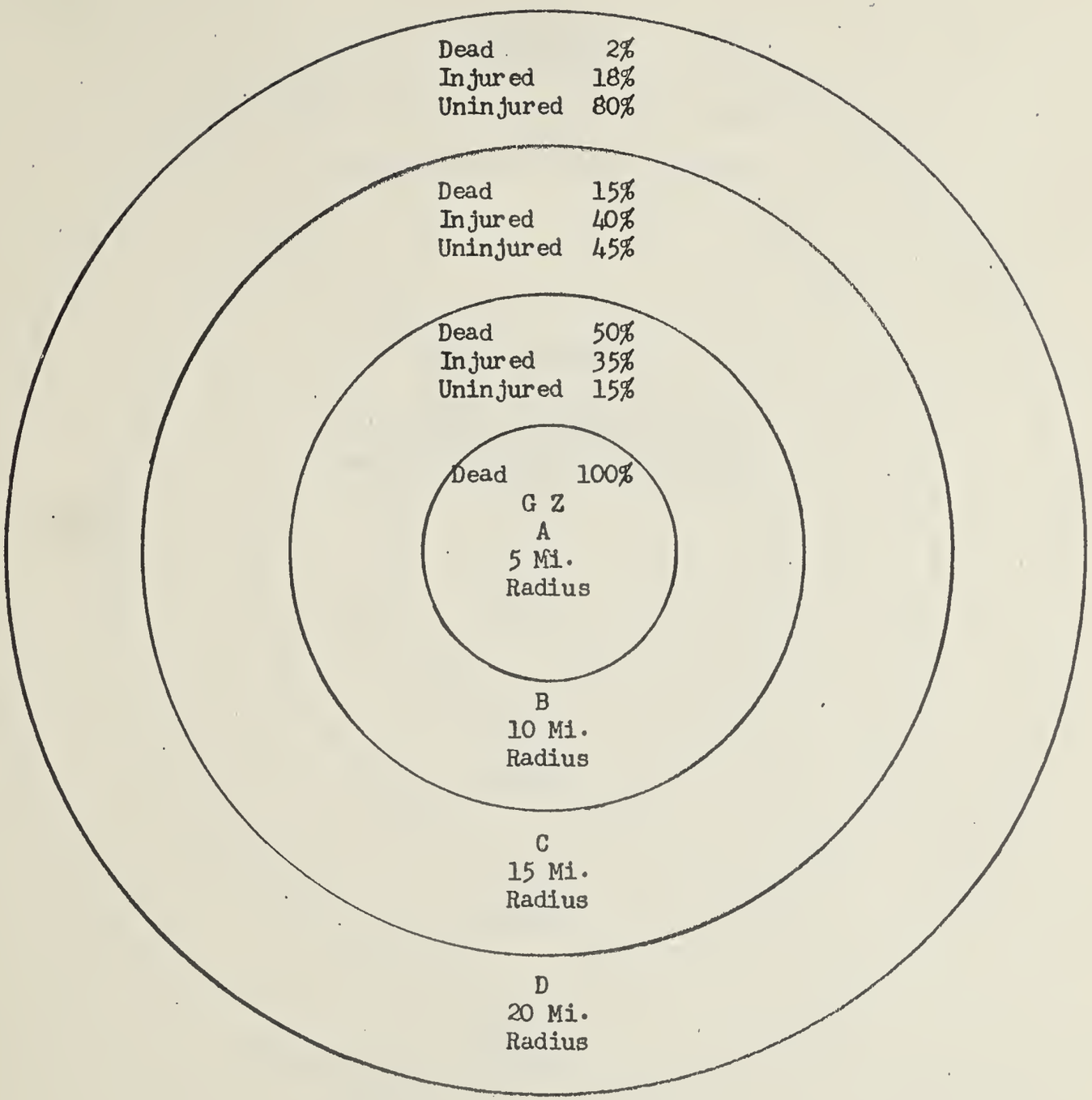


FIGURE 1

Estimated Percentages of Casualties that Would Result from the Surface (Ground) Detonation of a 20-MT Nuclear Weapon Under a Condition of No Warning

LIMITED FIRES OUTWARD TO 20 MILES

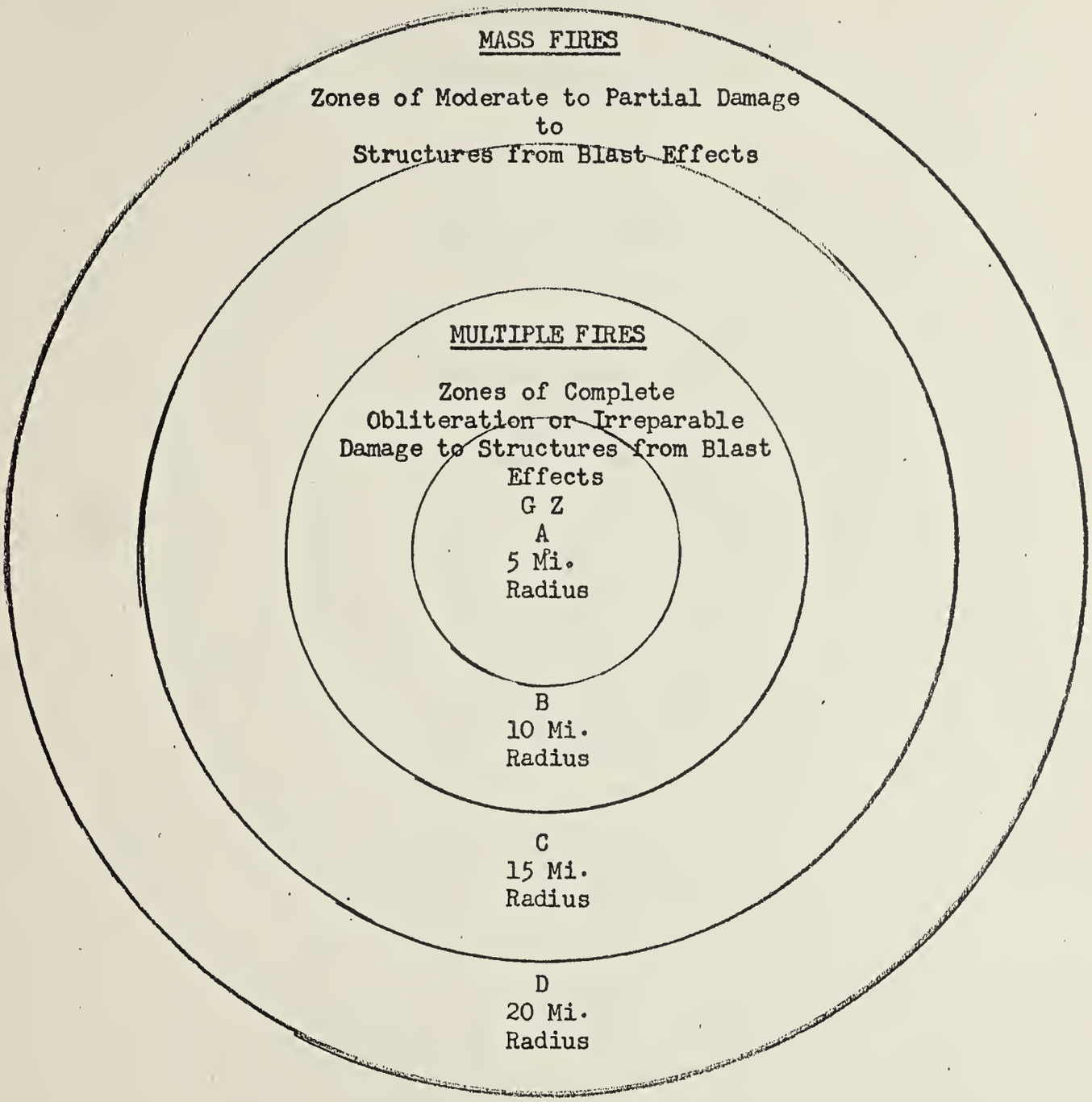


FIGURE 2

Extent of Fire Damage to be Expected from the Surface (Ground) Detonation of a 20-MT Nuclear Weapon

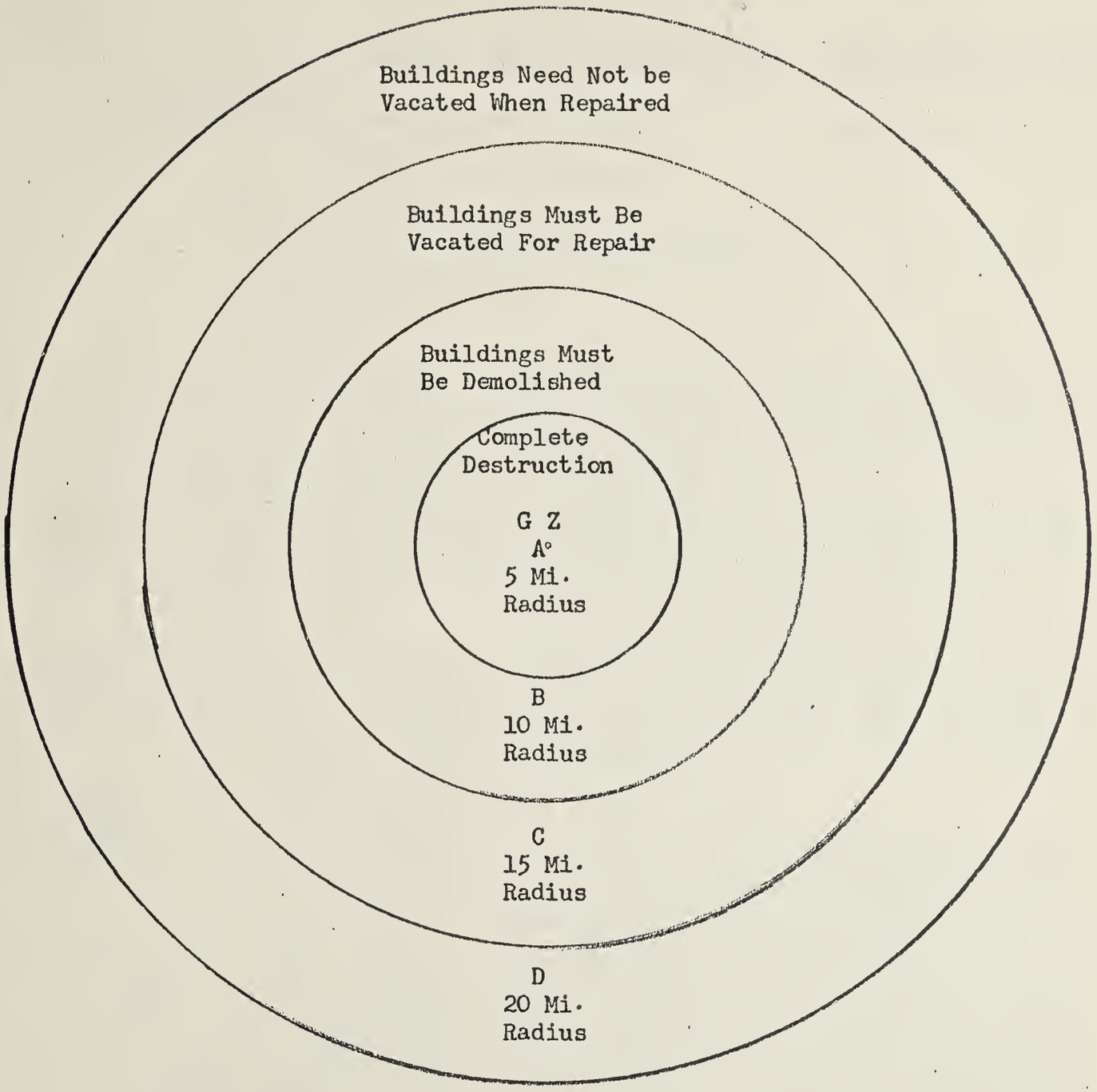


FIGURE 3

Estimated Degrees of Damage to Buildings that Would Result from the Surface (Ground) Detonation of a 20-MT Nuclear Weapon

civil defense
Technical Bulletin

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October 1955
Revised February 1956
(Reprinted May 1961)
RADIOLOGICAL DEFENSE SERIES

A DIGEST OF TECHNICAL INFORMATION

FALLOUT AND THE WINDS

This is one of a series of technical bulletins on civil defense against the radiological effects of nuclear weapons.

Radioactive fallout is the surface deposition of radioactive material which has been explosively distributed in the atmosphere by the detonation of a nuclear weapon. When a bomb is detonated at heights which allow the fireball to come in contact with the ground, great quantities of pulverized and vaporized material are carried up in the atmosphere. The cloud then contains a vast amount of radioactive dust particles of all sizes, from submicroscopic specks to visible grains or flakes. The larger particles settle to the ground rapidly, the smaller more slowly. The particles of earth are not in themselves radioactive, but fragments of bomb materials adhere to them and fall to the ground. This is fallout. (See Fig. 1.)

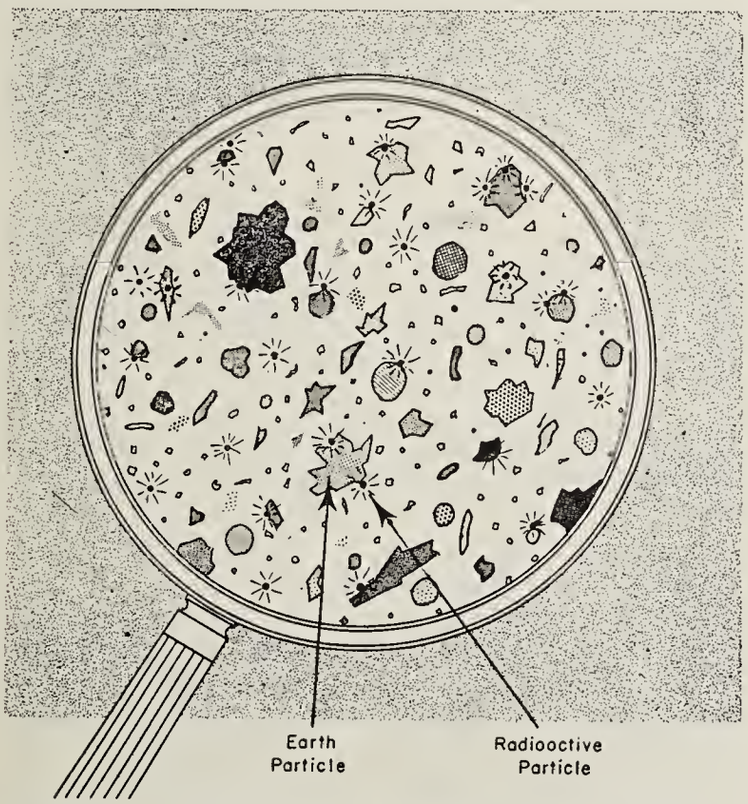

Figure 1. A portion of the mushroom cloud, magnified.

The radioactive particles formed from the bomb materials are themselves very small, and can remain in the air for a long time before settling to the ground. For this reason the cloud from a bomb detonated high in the air so that the fireball does not touch the ground, does not produce dangerous fallout.

Clouds produced by "A-bombs" of the type used in World War II generally do not rise above 50,000 feet. Photographs of the cloud produced by the first thermonuclear bomb at Eniwetok in November 1952 show that it reached a height of 25 miles, or about 130,000 feet. However, this does not mean that dangerous fallout comes from all altitudes up to the top of the cloud. It appears that the uppermost part may not contribute much to the overall hazard. Still, the evidence indicates that debris which rises to altitudes of at least 80,000 feet must be considered in attempting to explain the observed fallout from test detonations of the thermonuclear weapons. Figure 2 shows the comparative size of an A-bomb cloud, H-bomb cloud, and an ordinary thunderstorm cloud.

Rate of Fall of Particles

The particles carried up into the atmosphere by the detonation are acted upon by gravity and are carried by the winds. The wind directions and speeds usually vary from one level to another, so that each particle follows a constantly changing course, with changing speed, during its fall. The rate of fall depends upon the particle's size, shape, and weight, and the characteristics of the air. The stronger the winds in each layer, the farther the particles will be carried in that layer; but the faster the particle falls, the less influence the wind will have on it and the closer to ground zero it will land. The higher the altitude at which its begins to fall, the longer it will be carried by the wind, and under most conditions—when the winds at different altitudes do not oppose one another—the farther it will travel. Figure 3 shows the effects of various combinations of particle size and wind distribution.

Source of Wind Data

High altitude wind observations are taken at many stations in the United States operated by the Weather Bureau, Army, Air Force, and Navy. At these stations, small lightweight radio transmitters attached to helium-filled bal-

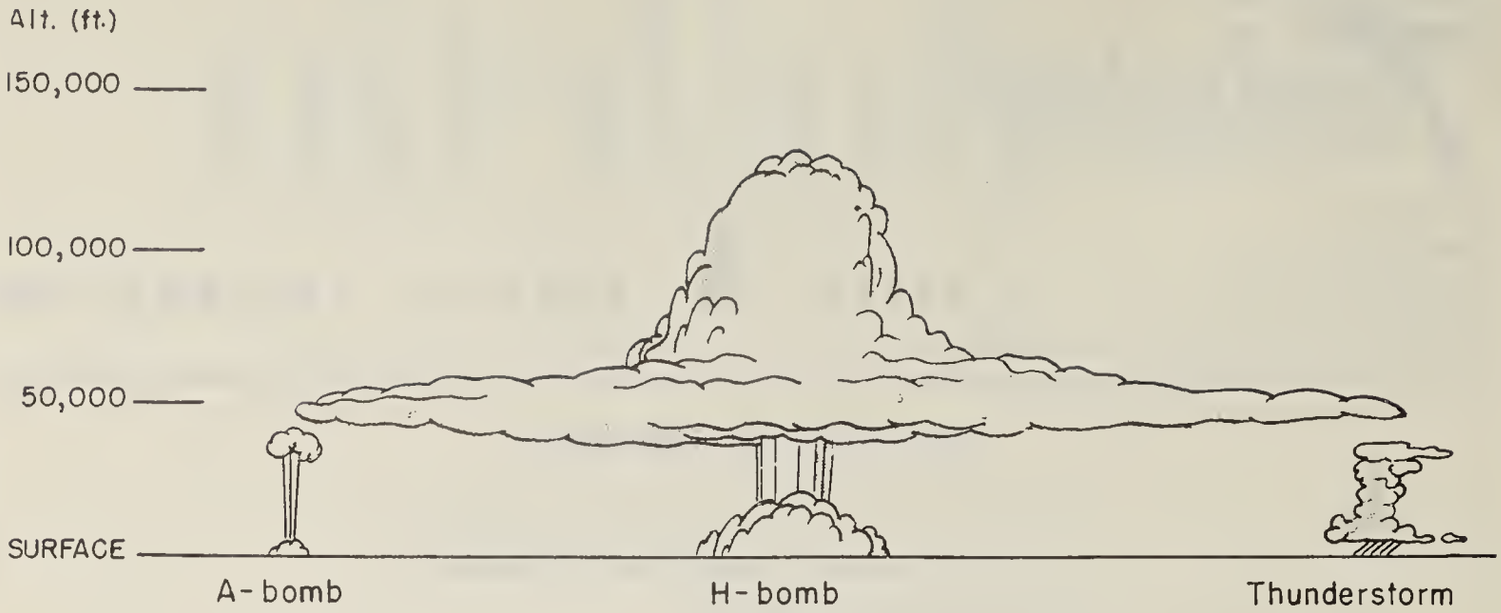

Figure 2. Comparative size of A-bomb mushroom, H-bomb mushroom, and ordinary thunderstorm cloud.

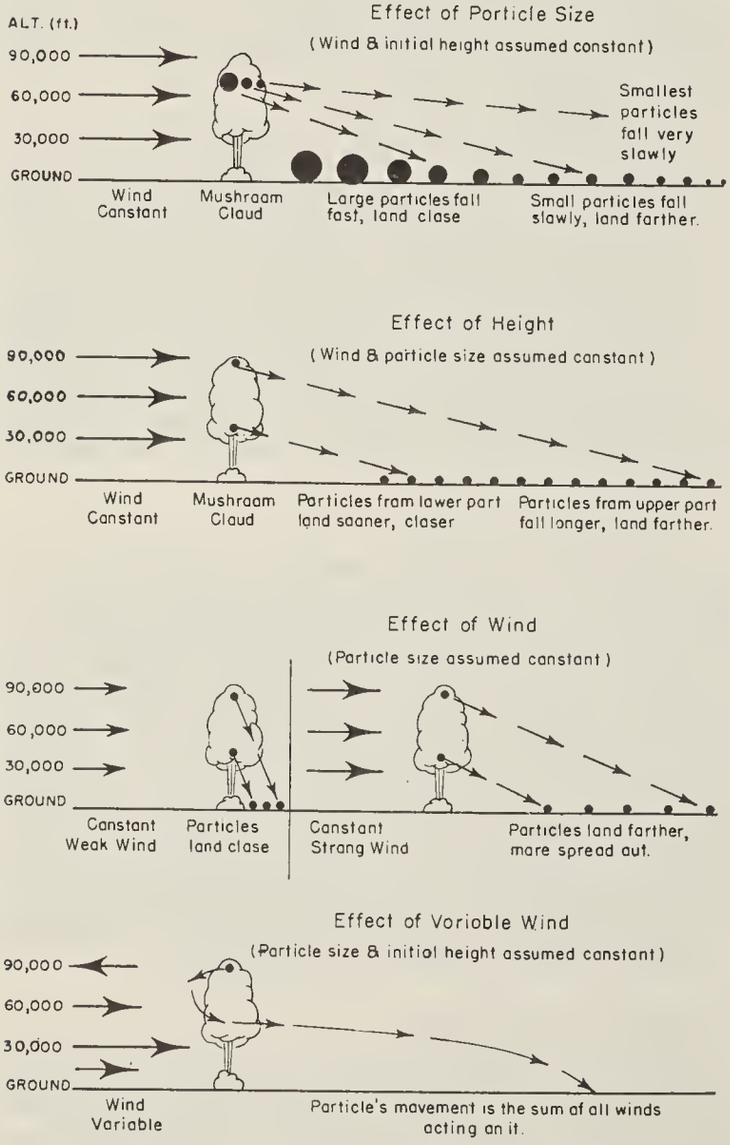

Figure 3. Factors affecting distribution of radioactive particles.

loons are sent aloft several times daily and their positions recorded at frequent intervals by direction-finding receivers. Altitudes of 80,000 feet or more are frequently reached. The wind data for each station at observation time are transmitted by teletype to all weather forecasting offices. Figure 4 indicates the locations of the high altitude wind reporting stations in the United States.

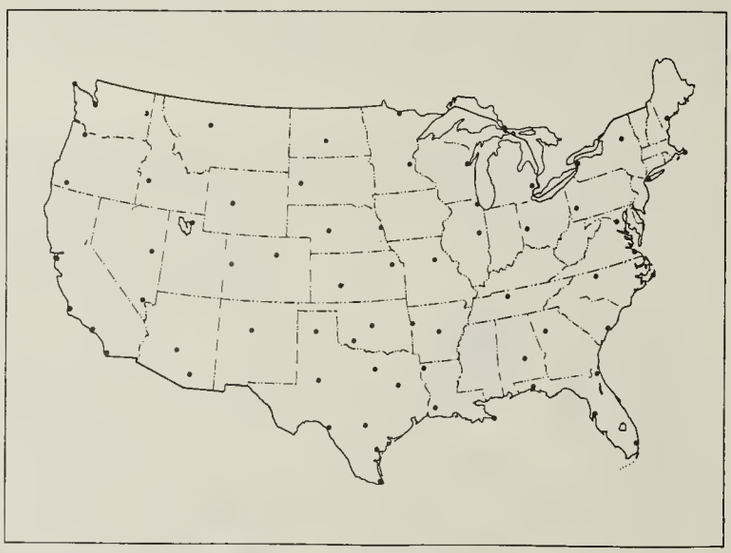

Figure 4. High altitude wind reporting stations in the United States.

Prediction of Fallout Areas

Weather Bureau reports can be used to predict probable areas of fallout from a nuclear bomb. The observed or predicted wind in each layer of the atmosphere can be translated into a definite horizontal movement for each size of particle. The horizontal movements imparted to the falling particles in all layers of the atmosphere can be added together to predict their total travel. Although particle sizes and altitudes will not be known in advance of an attack, a useful estimate can be made of the direction and rate of spread of the fallout under existing wind conditions. Figure 5 is a simplified drawing indicating the

sector of fallout from the stem and top portion of the cloud from all levels 5,000 feet to 80,000 feet.

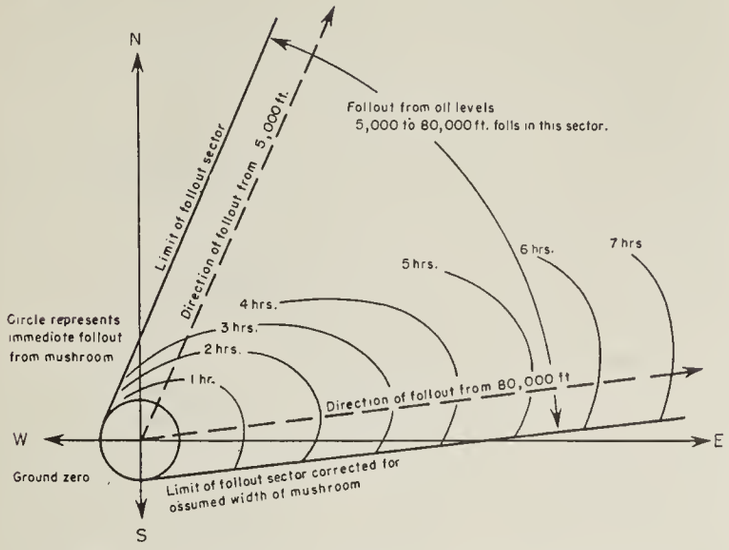

Figure 5. Sector of fallout from stem of cloud.

The U. S. Weather Bureau issues forecasts twice daily for all critical target areas of fallout direction, distance, and arrival time. On February 1, 1956, the service was expanded to cover all areas of the country. This information provides to local, State, regional, and national civil defense, the data necessary for the construction of fallout plots. Details of the program are described in FCDA (OCDM) Advisory Bulletin No. 188, dated May 25, 1955, and Supplements Nos. 1, 2, and 3, dated August 16, September 27, 1955, and January 26, 1956. Instructions are included for constructing fallout plots from the Weather Bureau forecasts.

These fallout predictions are useful for civil defense planning, but limitations must be recognized. Forecasts are released only twice a day. Therefore, at certain times the fallout plots will be based on wind measurements more than 12 hours old.

Prediction of Radiation Levels

Wind data alone, of course, do not indicate the levels of radiation to be expected. Levels would depend on such things as altitude of the burst, amount of energy released, the nature of the ground surface, height to which the cloud rises, and the bomb design. These things could not be known before the attack—making it difficult to predict accurately the radiation levels that would result.

Data for forecasting levels of fallout radiation from a given weapon are limited. However, some information was obtained from the Pacific "H-bomb" tests of the Atomic Energy Commission. According to the AEC, ". . . it is estimated that following the test explosion on March 1, 1954, there was sufficient radioactivity in the downwind belt about 140 miles in length and of varying widths up to 20 miles to have seriously threatened the lives of nearly all persons in the area who did not take protective measures." The device that produced this pattern was in the multimegaton range. However, it cannot be expected that other bombs of the same power would necessarily produce the same fallout pattern or radiation levels. The Bikini "cigar-shaped" pattern is only an example of what is possible. Even with exactly the same type, power, and altitude of detonation, different wind conditions would have produced a different fallout pattern, possibly of irregular shape.

The speed and vertical shear of the upper air winds will affect the concentration of radioactivity on the ground. A fallout pattern under conditions of strong winds aloft would differ from that of weak winds in two ways. The strong wind would spread the material over a larger area, tending to reduce the concentration close to the source, and at a given distance the fallout would arrive sooner and would have had less time to decay. Therefore, the area of dangerous contamination would likely extend farther from the source in stronger winds.

Obviously, the length of time required for the bulk of dangerously radioactive dust to be deposited on the ground will depend on the yield of the bomb and the size of the particles. Referring again to the March 1, 1954, Bikini test, it appears that hazardous material continued to fall in some areas for at least 12 hours after the burst. In some instances, it might continue for 24 hours.

Precipitation in a fallout area will affect the radioactive deposition. Raindrops and snowflakes collect a large proportion of the atmospheric impurities in their paths. Particles of radioactive debris are "washed" or "scrubbed" out of the air by precipitation. The result is that contaminated material, which would be spread over a much larger area by the slower dry weather fallout process, is rapidly brought down in local rain or snow areas. It is conceivable that hazardous concentrations can occur in rain areas where ordinary fallout estimates might indicate a safe condition. This scrubbing reduces the amount of contamination left in the air to fall out farther downwind.

Terrain features will cause a variation in degree of deposition. Hills, valleys, and slopes of a few hundreds of feet would probably not have a great effect on the fallout radiation levels. By receiving more fallout on the side facing the surface wind, large mountains or ridges could cause significant variation in deposition. This is true for both dry weather fallout and "rainout."

Climate and Wind Considerations

It is highly questionable whether the Bikini fallout patern should be applied to regions not in the tropics. The climate and winds of the United States are generally different from those of Bikini. The United States has a variety of upper air winds. However, wind conditions similar to those accompanying the Bikini test do occur in the United States, particularly in the summer months. During the winter, spring, and fall seasons, the United States winds are primarily the "prevailing westerlies." By this it is meant that the winds over the United States blow more frequently from the western quarter than from any other quarter of the compass. The westerlies in the middle latitudes become increasingly predominant with increasing height up to about 40,000 feet. At 5,000 feet the winds are from the western quadrant about half the time; while at 30 to 40 thousand feet, they are from that quadrant about three-fourths of the time. Above 40,000 feet, the percentage of westerly winds again decreases.

It is implied in the above paragraph that predominance of westerly wind direction changes with the seasons. Upper winds blow from the west more often during winter than during summer. The increase in frequency of other directions in the summer is more pronounced in the southeastern portion of the country, where directions become variable at all levels. Along the Pacific Coast, the winds blow less constantly from the west than in other sections of the country. Southwesterly and northwesterly winds are more common. Above 60,000 feet, easterly winds occur frequently in all seasons and are the rule in summer over most of the United States. Figure 6 indicates the percentage of time that winds blow from the western quadrant at 40,000 feet over the United States in the winter and summer seasons.

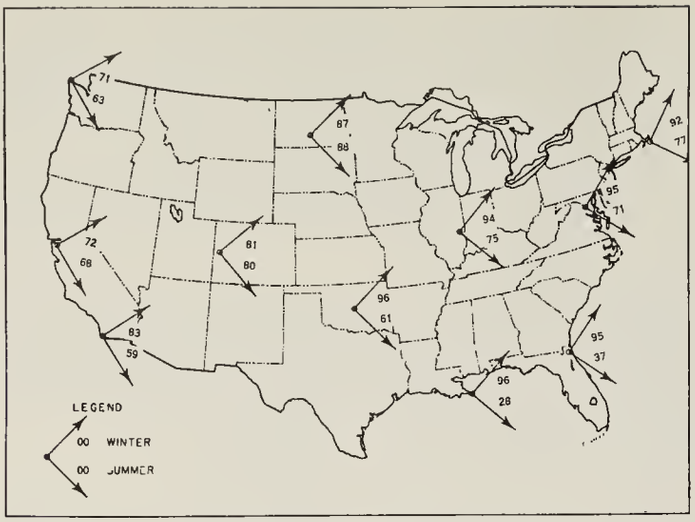

Figure 6. Percentage of time with westerly winds at 40,000 feet.

In describing direction of fallout from the point of detonation (GZ—Ground Zero), the terms "upwind" and "downwind" are often used. The downwind direction is the direction toward which the wind blows. "Upwind" means against the wind, just as "upstream" and "downstream" are related to river currents. When applied to fallout, the terms "upwind" and "downwind" will apply to the resultant or total effect of all the winds through which the particles have fallen. An upwind component results from the very rapid expansion of the cloud in all directions immediately after detonation. The disturbances at the time of the explosion will deposit radioactive material in upwind and crosswind directions for relatively short distances from ground zero.

All civil defense personnel should be cautioned against using surface wind directions as an indication of direction of flow at levels high in the atmosphere. The direction of fallout is determined by winds up to at least 80,000 feet above the surface. Winds in the upper air frequently are different from those at the surface. It is not at all uncommon to have east, south, or north winds at the surface and westerly winds aloft. There is no correlation between the two.

It has been pointed out that, in considering the possible area of fallout, wind speed is as important as wind direction. The direction determines the sector to which particles are carried, and the speed governs how far they will travel before coming to earth. The average wind speed at different heights over the United States is shown in the accompanying table.

Average Wind Speeds Over The United States

Height (ft.)	Winter (mph)	Summer (mph)
5,000	25	15
10,000	35	19
20,000	55	25
40,000	80	45
80,000	30	20

Wind speeds over the United States generally are less in summer than in winter at all heights and above all areas. The only exceptions would be during the passage of hurricanes or tornadoes which produce very strong surface winds in the warm season. This difference between seasons is greatest in the southeastern portion of the country, where winds become particularly light and variable in the summer. During the winter, upper winds along the Pacific Coast generally have lower speed than in any other section of the United States. Winds increase with altitude from the surface up to a level between 30,000 and 40,000 feet. Above this level they usually decrease in speed until, at 60,000 to 80,000 feet they become relatively light. Figure 7 indicates the variation of wind direction and speed in the United States at 40,000, 50,000, 60,000, and 80,000 feet.

The winds of greatest speed usually occur between 30,000 and 40,000 feet, winds exceeding 50 mph being the rule all over the country in winter and in the northeast in summer. In this layer, winds greater than 100 mph are at times experienced over all areas of the United States, but have been observed most often over the northeast, where they are found about 25 percent of the time. In this northeastern area, winds of 200 mph occur frequently and even speeds of 300 mph are observed on rare occasions. The high speed winds usually occur in narrow meandering currents within the broad belt of middle-latitude westerly winds, and are called "jet streams." Figures 8 and 9 indicate the percentage frequency of occurrence of winds greater than 50 knots (58 mph) and greater than 100 knots (115 mph) for the United States by seasons.

The strongest winds encountered by a falling particle have the greatest proportional influence on its total movement. The strongest winds are usually at altitudes in the vicinity of 40,000 feet. These winds would determine largely the general direction and length of the fallout area, although all the winds up to more than twice that height could be effective.

Fallout patterns over the United States, as has been stated, would probably differ in shape and extent from Bikini patterns. In the northern half of the country considerably longer patterns would be expected, spreading toward the east because of the strong upper air westerly winds. The passage of low pressure areas would cause shifts from a more northeasterly to a more southeasterly spread of the fallout pattern from one day to another. In the summer, particularly in the southern part of the country, a great variety of patterns might be expected with a broad irregular spreading in all directions in some cases, and elongated streaks in others. It should be remembered also, that in an area where several target cities are situated within a few hundred miles of one another, fallout from more than one detonation might occur at the same place.

Variation of the winds by day and night has little effect on factors that determine fallout patterns. Winds a few hundred feet above the ground frequently change, from night to day, but those higher up, which have the greatest effect on the fallout pattern, do not follow a daily cycle. Cloudiness or fog alone are not believed to have a marked effect on fallout, although the combination of fallout particles with cloud droplets may result in a faster rate of fall. Some cloud types also have upward and downward air currents. The downward currents might tend to bring some of the radioactive debris down more rapidly than it would otherwise settle.

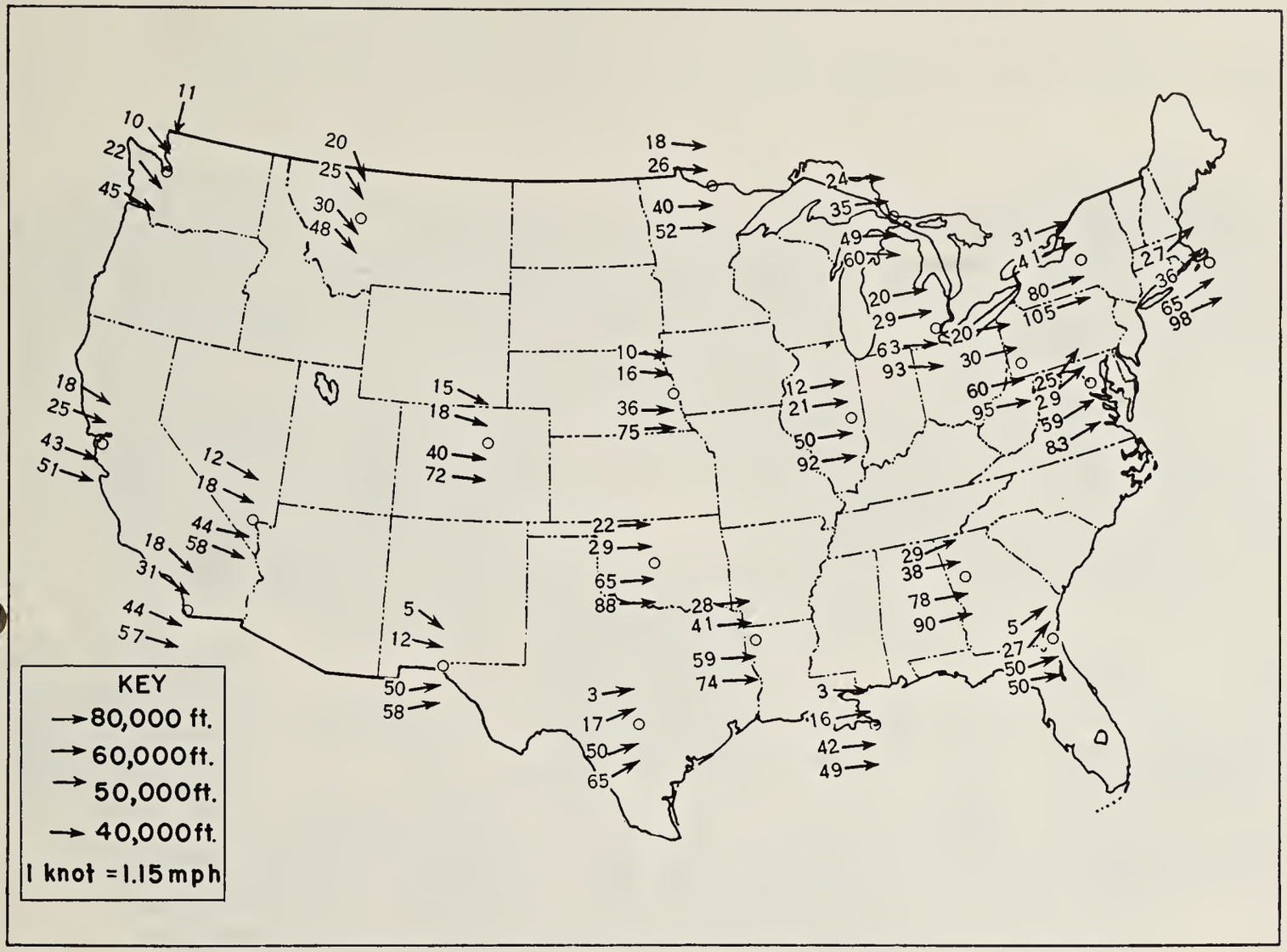

Figure 7.—Average wind direction and velocity for January. (Based on 5 years of data).

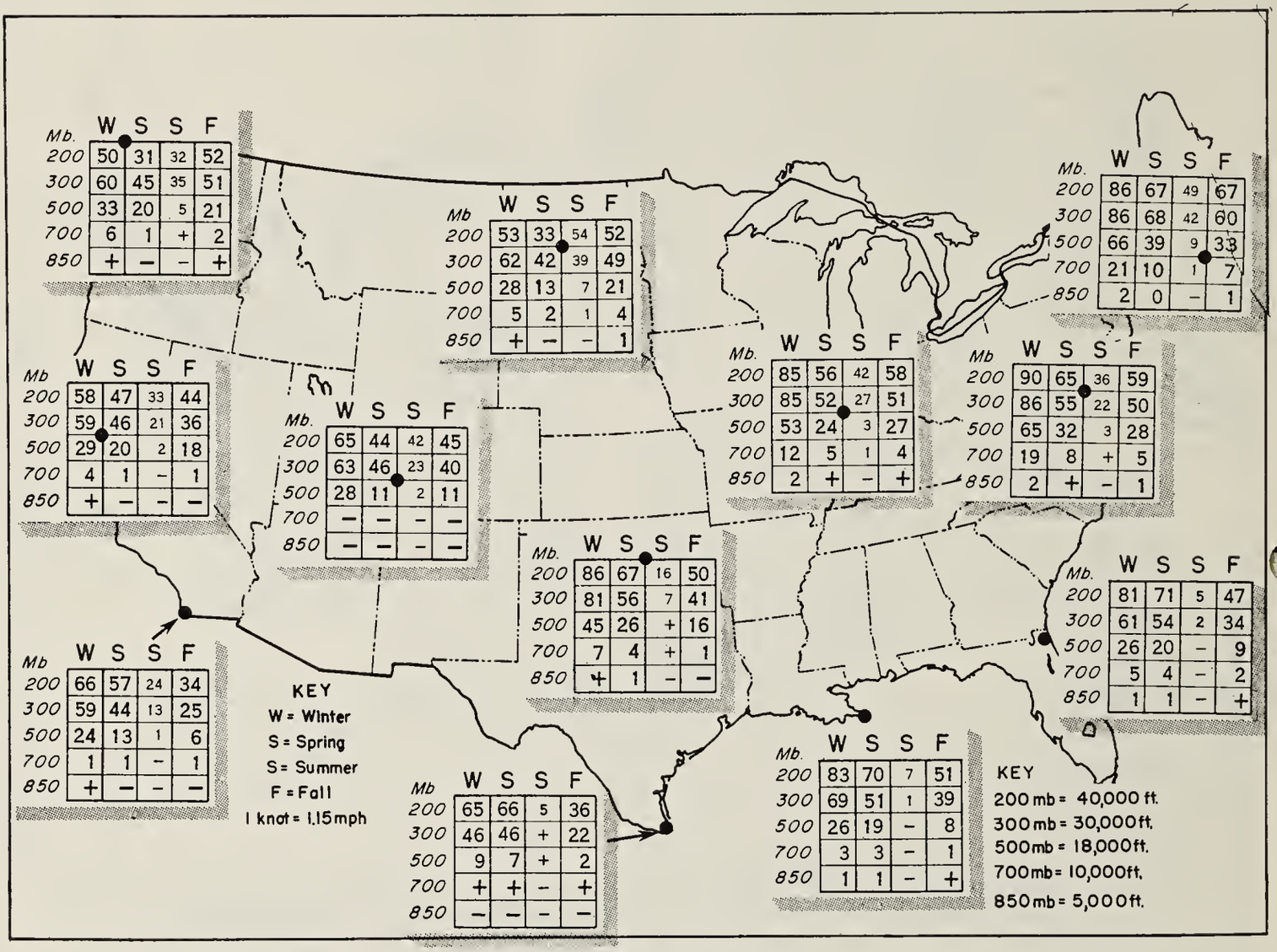

Figure 8. Percentage frequency of winds over 50 knots (58 mph).

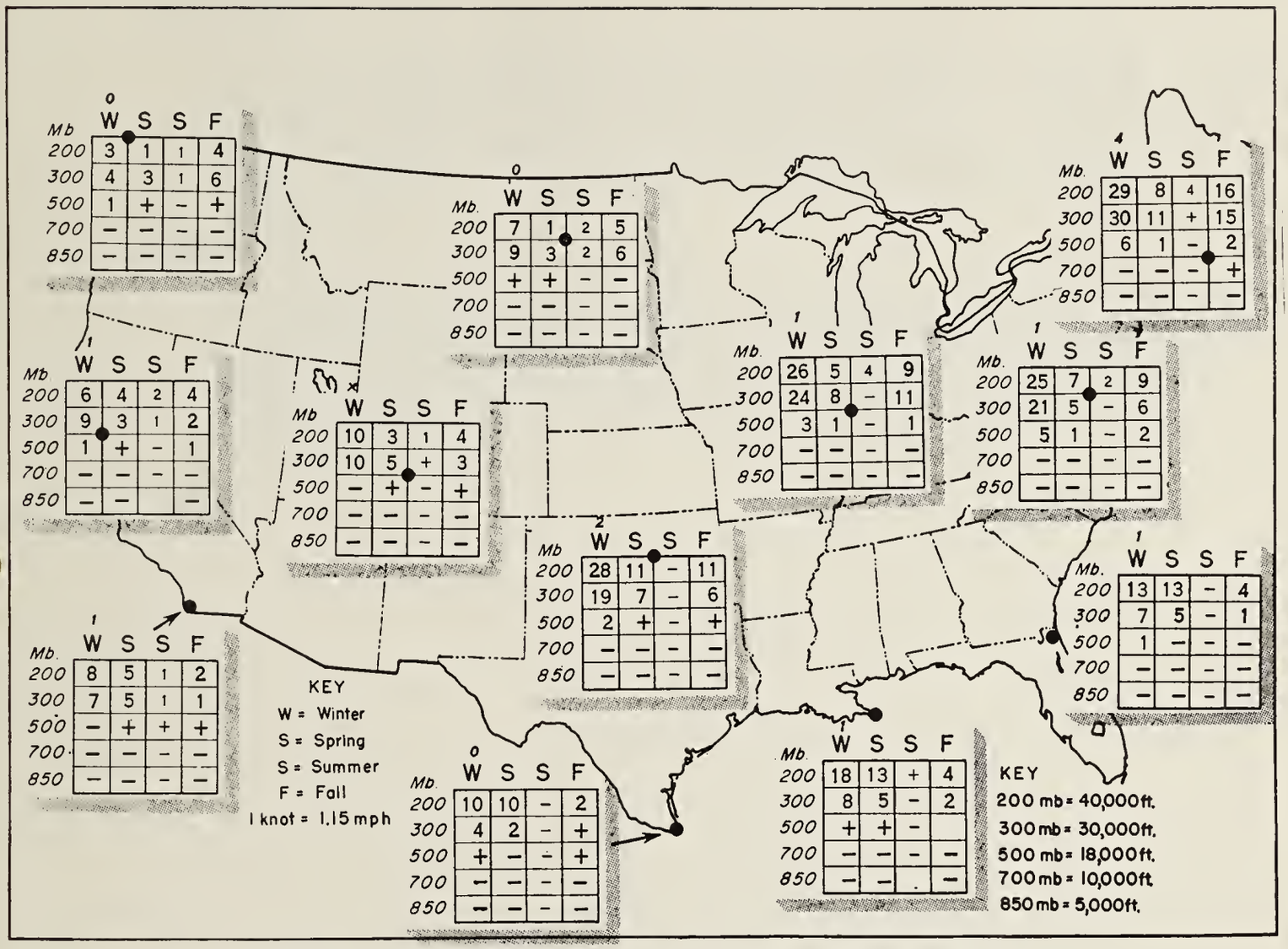

Figure 9. Percentage frequency of winds over 100 knots (115 mph).

GPO 810737

300 FALLOUT

310 General

Fallout is caused by the large amounts of dirt and debris carried into the air by an atomic explosion, becoming radioactive and falling back to the earth.

320 Drift

In plotting a pattern for fallout we assume that the wind is blowing in only one direction at 15 miles per hour. Fallout would tend to settle in a cigar shaped pattern in the downwind direction. Winds do not all blow in the same direction though and the actual pattern is very irregular. Therefore it is necessary to carry out local monitoring.

330 Protection

There is protection from fallout by either evacuation or shelter. If enough warning is given before the attack as many people as possible should be removed from the area where it is thought that fallout will settle. If there is not enough time for evacuation, everyone should take shelter so that the debris, when it falls, will not be able to reach them directly.

410 CD V-457 Training set, Radiological Monitoring

Demonstration equipment for training of radiological monitors in the nature of beta and gamma radiation, e.g., propagation, absorption, shielding, and scatter, and for training in the measurement of ionizing radiation with a Geiger-Mueller type survey instrument (CD V-700 is this type). The set consists of a power-operated instrument giving visible indication of radiation rates by means of a meter and a flashing light, and audible indication by means of a built in speaker. A storage shipping case is provided for the instrument, assorted sources, demonstration equipment, and 10 CD V-787's (Food and water comparison standards).

420 Radiological Survey Meters

Survey meters are designed to detect nuclear radiation and to measure the dose rate. Some of these meters measure gamma rays only, others are beta-gamma discriminating.

421 CD V-700 Geiger Counter, probe type, beta-gamma discriminating, 0-0.5, 0-5, and 0-50 mr/hr.

A beta-gamma discriminating instrument designed to be sensitive to low levels of radiation only. It is suitable for:

a. Monitoring of personnel, food and water when used in a shielded facility or an area of low radiation background.

b. Continuing follow-up monitoring of areas for human habitation and food production.

c. Training which must be carried on in the areas of low radiation dose rate.

422 CD V-710 Gamma only, 0-0.5, 0-5, and 0-50 r/hr.

A medium range gamma survey meter for use by radiological monitors for the major part of their operation in the period following the attack. This instrument was designed for ground survey but it can serve quite well as interim equipment for aerial measurements.

423 CD V-720, Beta-gamma discriminating, 0-5, 0-50, 0-500 r/hr.

A high range beta-gamma survey meter required for use by highly qualified monitors when it is necessary to make measurements in areas of extremely high contamination, and for detecting high level beta radiation. It has a discriminating shield to permit the measurement of gamma only or of combined gamma and beta radiation.

430 Radiological Dosimeters

Dosimeters detect and register the total accumulated gamma dose.

431 CD V-138 Dosimeter, gamma only, 0-200 mr.

A training and peacetime dosimeter for use by radiological defense personnel to keep them continually informed of their radiation exposure during training and operational exercises, and to generally familiarize them with the functions and characteristics of dosimeters. This dosimeter is of the self reading "quartz fiber" type. It is to be charged with Dosimeter Charger CD V-750.

432 CD V-730 Dosimeter, self reading, gamma only, 0-20 r.

An instrument for measurement of radiation exposure of radiological monitors and workers exposed to radiation. It is of the self indicating quartz fiber type, is carried like a fountain pen which it resembles in size and shape, and is identified by the 0-20 r. range. It is charged with Dosimeter Charger CD V-750.

433 CD V-740 Dosimeter, self reading, gamma only, 0-100 r.

A dosimeter similar to CD V-730 in function and design, differing only in range, 0-100 r.

440 CD V-750 Radiological Dosimeter Charger

A device for supplying the needed electric power for charging (setting to zero) dosimeters CD V-138, CDV-730, CD V740, and CD V-742.

450 CD V-786 Source Set, Co60, 12 Sources totaling approx 30 mc.

Low activity radioactive sources for demonstration purposes and exercises in radiological defense training.

460 CD V-787 Food and Water Comparison Standard

Comparison standard for food and water contamination measurement.

470 CD V-791 Source container, small, lead.

Container for carrying small Cobalt 60 sources required for monitor training.

480 CD V-792 Source container, medium, lead

Container for storing small Cobalt 6o sources required in monitor training.

500 RADIOLOGICAL MONITORING

510 Responsibilities: Each Section Foreman during a warning or attack will be responsible for:

511 Monitoring all sections of State Highway which are presently his Maintenance responsibility.

512 Placing of signs and/or barricades as required to define the limits of unrestricted highway travel.

513 Reporting radiological monitoring data and sign or barricade locations to Division or District Headquarters.

514 Providing the best possible protection against contamination by fallout of Highway equipment and personnel under his control.

515 Determining by monitoring in the post attack period the degree of contamination of section maintenance equipment and starting decontamination procedures when feasible.

516 Reporting status of equipment to Division or District Headquarters.

517 Maintaining individual radiation exposure records for all personnel engaged in monitoring activities.

518 Monitoring of section crew personnel after operations which would expose them to radioactive dust or fallout particles.

520 Procedures

521 Strategic Warning Period

This is a period when there is a strong indication of a possible attack on the U. S. in advance of its launching. Increased tension in the international situation coupled with other intelligence information, could result in such an emergency warning period being declared. Such a declaration would come from the Federal Government and be transmitted down through Highway Department channels. Upon being advised of a Strategic Warning Period, a check of operational readiness should be made and steps taken to increase it, such as:

1. Review your family plan making sure each member of your family knows what actions to take at all times.

2. Issue monitoring instruments to individual monitors, if not already issued, with instructions for instruments to be kept available at all times.

3. Double check instruments for readiness. Obtain extra sets of batteries.

4. Issue personal dosimeters with instructions to wear them at all times. Make sure dosimeter is zeroed or reading is recorded when issued.

5. Keep mobile equipment full of fuel and ready for use on short notice.

6. Have monitors take radio-equipped vehicles that would be used in monitoring home at nights and on weekends.

7. Store equipment under cover when not in use.

522 Tactical Warning Period

This is a period when attack is considered a certainty and enemy planes and/or missles are on the way. This warning period could be from a few minutes to 3 or 4 hours and may or may not be preceded by a Strategic Warning Period. A tactical warning would be received through Civil Defense warning devices or over the State Highway Department communications system, or both. Actions to be taken upon receipt of a Tactical Warning are:

1. Follow local civil defense instructions.

   a. If in a pre-planned evacuation area, this would consist of immediate evacuation by the best available means. Time and situation permitting, rediological instruments should be obtained prior to evacuation. Your family plan should cover actions to be taken by all members of your family at any time of the day a tactical warning occurs. In the event the family is separated at the time of or during evacuation, provisions for re-assembly of the family at some pre-arranged spot, such as the home of a friend or relative located beyond the evacuation area, is recommended. After evacuation, report to the nearest Highway Department headquarters or operating facility.

   b. If not in a pre-planned evacuation area, take the following actions:

      (1) Time and situation permitting, obtain radiological instruments (if not already in your possession).

      (2) Put road equipment under best available cover if not used for transportation home.

      (3) Return home and take necessary action for personal and family survival. Use Highway equipment if more suitable method of transportation is not available. Place vehicle under cover.

      (4) When at home check radiological instrument operability and prepare for use.

      (5) Wear dosimeter at all times.

      (6) After family survival has been arranged, report to your Maintenance Station and establish radio contact with District Headquarters for further instructions.

(7) If contact with District Headquarters cannot be established, await Conelrad informational broadcasts and take appropriate action.

523 Attack Without Warning

1. Take best available protective cover.

2. If driving a vehicle, and the light from the explosion is observed, pull to the side of the road, get body and head as low as possible and cover head with arms for protection from possible blast effects such as broken glass and flying debris.

3. To the extent possible, make the following observations and report to your District Headquarters.

   a. Time of explosion.

   b. Direction of explosion.

   c. Monitor's location when observations were made.

   d. Blast effects at monitor's location.

   e. Heat effects at monitor's location.

   f. Weather conditions.

4. If time and situation permit, obtain radiological instruments (if not already in your possession) and return home by best means to take necessary action for personal and family survival. Generally, there would be at least one hour to do this before radioactive debris would begin to fall back to the ground. An initial location close to the explosion would prohibit returning to a home located in the direction of the explosion. In this event, proceed by the best available means away from the explosion and report to the first operating Highway Department installation.

5. When in a shelter area at home or elsewhere, check and record radiation levels periodically both inside and outside the shelter. Protect yourself and the instrument from contamination by suitable covering if readings are taken outside during fallout. Wear your dosimeter at all times.

6. At such time as your meter readings indicate that the radiation intensity had leveled off or begun to decrease, it can reasonably be assumed that all fallout in your immediate area is down. When this has occurred and the radiation outside the shelter is 3 r/hr or less, take the following actions:

   a. If radio equipped vehicle is in your possession, contact Highway District Headquarters and, unless instructed otherwise, proceed with pre-planned monitoring.

b. If radio equipped vehicle is not in your possession, start monitoring and proceeding along the route which will take you to the storage area of the radio equipped vehicle, which normally would be the maintenance station. Unless you encounter radiation levels in excess of 3 r/hr, proceed to the radio equipped vehicle and contact District Headquarters. If radiation levels in excess of 3 r/hr are encountered, return to your shelter and wait for decay to reduce the radiation level to 3 r/hr and then proceed to the radio equipped vehicle. CAUTION: Continually check your dosimeter and do not willingly expose yourself to an accumulated dosage of over 25 r. during the first 24 hours.

c. If initial monitoring indicates maintenance station and adjacent area is radiologically safe, contact members of section maintenance crew and instruct them to assemble at the station at or before D+1 (1 day or 24 hours after explosion).

7. At or before D+1, if initial monitoring indicates that levels of radiation in the area are such as to permit safe pursuit of assigned monitoring duties and if not otherwise instructed by District or Division Headquarters, proceed with monitoring of highway and equipment within the maintenance section limits.

530 Monitoring and Related Operations

531 Highway Monitoring

Monitoring of highways within the limits of each maintenance section should be conducted from a base of operations, normally the section maintenance station, and proceed towards the point of explosion. The survey should be conducted in a radio equipped vehicle by a team consisting of a driver-recorder and a monitor. If there is a shortage of monitors, the most important highways should be monitored first.

1. Proceed along each section of highway until radiation intensity requiring restricted travel, as shown on the attached table, is reached. Meter readings within the vehicle may be used as approximate indications, but all readings used to determine the limits of restricted travel should be taken in the open. When the reading within the vehicle approaches the critical reading, stop the vehicle and take a reading at a point on the highway center at least 15 feet from the vehicle. The recorded reading should be an average of four readings at 90° to each other about the point.

2. Set up signs and/or barricades as near the limit of unrestricted travel as possible, conforming to standard practices governing visibility, hazards and convenience to the traveling public.

3. As each sign and/or barricade is place, report immediately by radio to District or Division Headquarters, giving:

a. Highway number

b. Mile point at sign and/or barricade location.

c. Time barrier placed.

d. Level of radiation at barrier point.

4. If radiation level does not require closure of the section of highway being surveyed, report this to District Headquarters giving:

a. Highway number and section

b. Time survey completed

c. Maximum radiation level encountered, if any.

5. Proceed with similar monitoring on other roads according to plan.

6. When monitoring has been terminated for the day, all data accumulated should be summarized and reported to District Headquarters including actions incidental to or resulting from radiological monitoring such as:

a. Summary of barrier data for all sections of highway surveyed.

b. Extraordinary traffic behavior.

c. Public reaction to barricaded roads.

d. Activities of others affecting highway operations.

e. Degree of contamination and availability for use of Highway Department road equipment located within the maintenance section boundaries.

f. Availability of section crew personnel .

532 Personnel Monitoring

All personnel exposed to radioactive fallout or debris deposited by fallout during their daily operations should be monitored with a CD V-700. If radiation is detected on their clothing or person, proper decontamination steps, such as disposal or washing of clothing and washing of contaminated body areas, should be taken.

533 Equipment Monitoring

1. All road equipment which was not under cover during the fallout period will undoubtedly be contaminated at least to the degree of the surrounding area. If the radioactivity is above safe levels, the equipment should not be used unless steps such as washing, steam cleaning, or even blowing off

with an air hose and wiping with rags, can be taken to remove the radioactive dust particles from the equipment. After decontamination, the equipment should be checked with a CD V-700 in much the same manner as used in monitoring personnel. Decontamination of equipment should be performed in an area that can be isolated unless there is some facility such as a storm drain or stream that can be used to dispose of the radioactive material removed from the equipment. If no such facility is available, the area used for decontamination should be monitored periodically and denied to the public by sign and/or barricade when unsafe radiation levels are reached.

2. Equipment which was garaged or covered in some other way during the fallout period likely will not be contaminated; however, this equipment should also be checked with a CD V-700 before using.

534 Precautions

1. Make sure that instruments are calibrated properly and in good working order.

2. Check and record dosimeter reading before leaving shelter. If there is a shortage of dosimeters, one per monitoring team can be utilized with all members of the team assumed to have received the same exposure as the person wearing the dosimeter. Under these conditions, the dosimeter should be worn by the meter reader.

3. Unless otherwise directed by their immediate superior, personnel should not be exposed to doses in excess of 25 r. in any one day, 100 r. in any one week, and a total exposure of 200 r.. If possible, exposure should be kept well below this.

4. Wear protective clothing if available; such as hat, gloves, boots, coveralls, etc. As radioactive debris normally would all have fallen to the ground at the time pre-planned monitor-duties are performed, some type of protective footwear which could be decontaminated or disposed of would be of first consideration, also, a protective foot mat which could be removed and washed or disposed of should be provided for the vehicle used in monitoring.

5. Do not contaminate instrument by placing it on ground or other contaminated surface.

6. Keep monitoring time and radiation exposure to minimum.

7. Check radioactivity of monitor's clothing and monitor vehicle after completing each monitoring assignment. Decontaminate or dispose of any articles of clothing or equipment showing excessive radioactivity.

535 Tips for Monitors

1. Wear dosimeters at all times and check regularly the accumulated dosage.

2. Keep accurate record of daily (24 hr.) dose of radiation accumulated by each member of the monitoring team.

3. Hold survey meter waist high when monitoring.

4. Record location, radiation intensity (meter reading), date and time.

5. In open areas record the average of four readings 90° to each other about a point.

6. Avoid taking readings in low spots, roadway cuts or high fills, or any other non-representative points, including "Hot Spots". The level of radiation at these points may differ significantly from that of the surrounding area.

7. Take meter readings at least 15 feet from vehicle.

8. Take readings at the center of the highway or street.

9. When monitoring personnel or equipment, do not contaminate probe by brushing it against contaminated clothing or surface. This can be avoided by taping a piece of plastic around the probe, taping the entire probe, or some similar method and then disposing of the material used to cover the probe.

536 Half Life

Half life is the length of time it takes for a radioactive element to lose half of its radioactivity. Although this half life is different for each element, the half life for all the atoms of one certain element is always the same.

In a nuclear explosion, the radioactive fallout you will be monitoring is composed of a great number of radioactive elements, each with its own half life. Many of the elements are very unstable and have short half lives. As a result the radioactivity drops off rapidly after the explosion. This complicates the monitoring because the radiation is dropping even while the monitoring is taking place. This rapid decrease in the radioactivity forces resurveys in order to have reasonably reliable intensity data to guide rescue, salvage and repair operations.

There is a simple rule of thumb that can be used to forecast the approximate rate of decay of radioactive fallout. This is called the 7-10 Rule and is explained as follows:

> If the time after the burst is increased by a factor of 7, the dose rate will generally decrease by a factor of 10.

For example, If one hour after an explosion the dose rate reading in a certain area were 1000 r/hr, 7 hours after the explosion, the

dose rate in the same area would be 100 r/hr. Or, every time the time is multiplied by 7 the dose rate is divided by 10.

800 DECONTAMINATION

There will be a large amount of radioactive material deposited on roofs and the ground from fallout. A flushing system, draining a safe distance away would help clean the roofs and shielded bulldozers could be used to scrape away contaminated soil from around buildings. Removing debris would be a big job in areas destroyed by blast and fire, but outside of washing exposed buildings and articles with water, there is little one can do about fallout except wait for the radioactivity to decay.

Radioactive fallout that comes in contact with the skin should be washed off as soon as possible as the material can cause severe burns. Clothes that become contaminated should be removed and washed or thrown away.

Time after Blast	METER READINGS (r/hr.)							
H + 1	100	202	267	320	375	565	750	
H + 2	43.5	87.8	116	139	163	246	326	
H + 4	18.9	38.1	50.4	60.4	70.8	106	142	
H + 6	11.6	23.4	30.9	37.1	43.5	65.5	87	
H + 8	8.2	16.5	21.9	26.2	30.7	46.3	61.5	
H + 10	6.3	12.7	16.8	20.1	23.6	35.6	47.2	
H + 12	5.1	10.3	13.6	16.3	19.1	28.8	38.2	
H + 14	4.2	8.48	11.2	13.4	15.7	23.7	31.5	
H + 16	3.6	7.27	9.6	11.5	13.5	20.3	27	
H + 18	3.1	6.26	8.28	9.92	11.6	17.5	23.2	
H + 20	2.7	5.42	7.20	8.63	10.1	15.2	20.2	
D + 1	2.2	4.84	5.87	7.04	8.25	12.4	16.5	
D + 2	.98	1.98	2.62	3.13	3.67	5.54	7.32	
D + 3	.59	1.19	1.57	1.89	2.21	3.33	4.42	
D + 4	.42	.85	1.12	1.34	1.57	2.37	3.15	
D + 5	.32	.646	.854	1.02	1.20	1.81	2.40	
D + 6	.26	.572	.694	.832	.975	1.47	1.95	
D + 7	.215	.434	.572	.688	.806	1.21	1.61	
D + 14	.093	.188	.248	.297	.348	.525	.697	
D + 21	.057	.115	.152	.182	.214	.322	.427	
D + 30	.037	.075	.099	.118	.139	.209	.277	
D + 60	.016	.032	.043	.051	.060	.091	.120	
D + 90	.01	.02	.027	.032	.038	.057	.076	

Note: Inside heavy lines are readings which are safe for unrestricted travel.

Form EP-1